Novel Applications of Neuralink in HealthCare - An Exploratory Study

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***Abstract*— Flexible electronics is most attractive in Internet-of-Things (IoT). Its footprint reaches various applications including healthcare application. Brain-Machine Interface (BMI) is a technology that offers unprecedented functionality for biomedical purpose in healthcare applications. Neuralink is recently popular that places more electrodes in our brain tissue. It is an implanted device on the brain to make the connection between human and computer. This paper focuses on the novel application of Neuralink to smart healthcare. These smart implantable devices send a prior notification to the doctors and guardian's smartphone regarding heart disease and paralysis.**

***Keywords* — Brain-Machine Interfaces, Neuralink, Healthcare, Internet of Things**

I. INTRODUCTION

Brain-Computer Interface (BCI) is a powerful technology that bridges the human brain and computer. It is otherwise called Neural Control Interface (NCI) or Direct Neural Interface (DNI), or Brain-Machine Interface (BMI). This domain is opted for researching, helping and repairing human cognitive functions [6]. It does not require any external devices to issue and complete the interaction. The research community first developed BCIs with bio-medical applications in mind, which led to the development of assistive devices. They facilitated the restoration of the mobility capacity of immobilized users and the replacement of the lossy motion feature.

The bright future of BCI has encouraged the research community to study the involvement of BCI in the lives of non-paralyzed humans. But the scope of the research has further expanded to include non-medical applications. More recent studies target individuals by exploring the use of BCIs as a novel input device and by investigating the generation of hands-free applications. The problem of BCI is poor information transfer rate (ITR). The BCI utilization for locked-in personas will not be able to manage ordinary communication. Even with the contribution of BCI in various domains such as advertising, industry, smart transportation, the BMI needs to defeat technical difficulties as well as challenges posed by user acceptance to deal with such newly discovered technology [2].

BMI is becoming increasingly popular as Big Name and successful Entrepreneurs like Elon Musk and a huge part of the scientific community is coming together to explore more about our Brain to advance current CPU technologies and open up the Pandora's Box i.e., our Brain. Throughout centuries Thinkers and Dreamers have always pondered over what our Brain is and its significance. Over the years, we have understood many mind-boggling facts about our CPU (the Brain) but as research progresses and BMI technologies become more channelized and transparent, we will understand the connection between our Brain and each part of our Body. This means we can solve the biggest of riddles in Healthcare and unlock our so-called Hidden potential in every human being.

II. RELATED WORKS

Innovations in the field of human brain research and its electrical activity by Han Berger are linked to the discovery of Brain-Machine Interfaces. He is also the reason for the development of EEG which leads to the breakthrough of recording human brain activity for the first time. This major discovery in Human Brain Mapping has made it possible to detect brain diseases. Berger's inspiration was Richard Canton who in 1875 discovered electrical signals in animal brains. EEG neuro-feedback has been in use ever since as one of the first common use of BCI technology.

When researcher Philip Kennedy implanted the first Brain-Machine Interface into a human being in 1998, it marked a significant development in Brain Mapping. But the BCI object was of very limited function and the only development technology-wise was the use of wireless di-electrode.

Cyberkinetics, a public traded company was formed by John Donoghue and his team, Brown University. The company aims to design a commercially viable BCI by the product name, BRAINGATE. Its first commercial product, NeuroPort was used by researchers from Columbia University Medical Center to monitor and record EEG with improved precision. The researchers noted that Neural Monitoring System (NeuroPort) has enabled them to identify micro-seizure activity before epileptic seizures among patients.

The number of developments that are taking place in the BCI domain is on course to make BCI a magic wand that can help us control objects with our mind by 2050. Maybe one day we can guide an outside object with our thoughts to consistently execute both our natural and our complex motions of daily life.

The concept of the Brain-Machine Interface is not new. There are already different forms of BMI that exist, like the ones that are implanted into your brain tissue and the ones that sit on top of your head. According to Zaza Zuilhof, nearly 220,000 hearing impaired has already been benefitted from Cochlear Implant (implants that translate audio signals into electrical pulses which are sent directly to our brain for sense) [5]. It is needless to say that most of the Brain-Machine Interfaces that were produced or developed first was for Medical Applications.In the article "The Brief History of Brain-Computer Interface", we can find the history of BCI and crucial information related to them. According to the article, BCIs research and development started after the Research on BCIs by the University of California in the 1970s. Neuroprosthetics applications continue to be the primary focus of BCI research and development as it promises the restoration of lost or damaged sight, hearing and movement. A Brain-Machine Interface doesn't measure the mind accurately; instead, it detects the change in energy radiation of Neuron's Activation Potential and uses them to recognize frequency patterns in the signals emitted by our brain. Matthew Nagle is the first human to ever receive a BCI implantation in June 2004; this marked a remarkable time in BCI development and increased hopes on BCI.BrainGate was implanted into him, a system composed of one hundred electrodes known as "invasive", that is to say, connected directly to the cerebral cortex, developed by Cyberkinetic the company in collaboration with Brown University's neuroscience department. This allowed Matthew Nagle to control a computer cursor and a robotic arm to control the TV and lighting, or to read his emails and play Pong. A research report on controlling a computer using BCI was demonstrated by Jonathan Wolpaw and his team of researchers at the New York State Department of Health's Wadsworth Center in December 2004. This study made participants hear a cap that contained electrodes that can capture EEG signals from our Motor Cortex (Movement). Wadsworth System monitors and detects EEG (ElectroEncephaloGraphic) activity from the scalp and records specific brain waves, from users wearing an electrode cap. An adaptive algorithm is made to analyze the output; it also focuses on signals that provide the greatest control as participants learn to use their thought to redirect a cursor on a monitor to a target screen. The algorithm adapts itself as the trainee improves in the task.

BCI has centred on control applications like cursors, paralyzed body parts, robotic arms, phone dialling, locking or unlocking etc., since the beginning of its development. In a recently published study by Dr Wolpaw's Lab real-time, two-dimensional cursor movement controls were achieved by a trained able-bodied and spinal cord-injured individual. This is comparable to studies that involved non-human primates with "implanted electrodes". It means a significant improvement in the performance of Non-invasive BCI which is because of improved changes in Signal Processing and the use of Adaptive algorithms. Studies also show that non-invasive BCI could one day support sophisticated tasks like controlling a neuroprosthetic arm or your phone. The four major components of BCI are signal acquisition, signal preprocessing, feature extraction, and classification. The architectures are shown in Fig. 1.

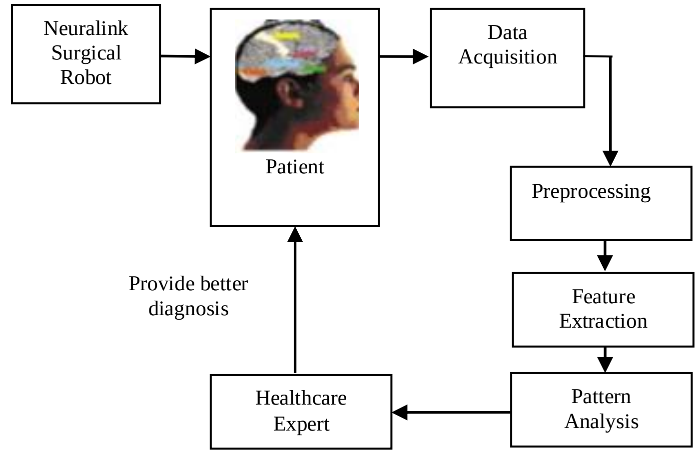

Fig. 1. Architecture of BCI

Diving deep into this, depression and similar disorders could be treated with deep electrical stimulation of the brain thus making the process of targeting specific parts of the brain viable to health professionals and diagnose which part of the brain is responsible. The stimulation of neural fibers carrying information from the primitive brain to the frontal lobe can be achieved by implanting an electrode into the brain while having a separate device incorporating a battery and a pulse generator implanted into the chest or abdomen with wires to the skull connecting the electrodes.

Thanks to the many advances made in recent years, a BMI not only restores lost faculties (movement, hearing and sight) but could also soon expand.

III. BRAIN-MACHINE INTERFACE

The brain-machine interface performs recording of brain signals and feeds to the machine to perform the intentional task. These signals are used for controlling an object or expressing an idea. The Brain-Machine Interface eliminates the need for typical information delivery methods by building a connection bridge between the human brain and the world. Employing this communication protocol, the Brain-Machine Interface manages the message transmission from the human brain and decodes their quiet thoughts. This is why the Brain-Machine Interface can help handicapped people in telling or writing their opinions via various methods such as in silent speech communication, or semantic categorization.

Earlier, BMI applications aimed at providing an alternative communication channel for persons with disabilities who have mobility or speech issue. But today, the Brain-Machine Interface has also entered the world of healthy people. It is now functioning as a physiological measurement instrument that uses a variety of information such as cognitive, emotional, or efficacy status [4]. Various research contributions to BCI are given in Table I.

TABLE I.
RESEARCH CONTRIBUTIONS TO BCI

Year	Contribution to BCI
1970	Implantation of BCI sensors in rats, mice, monkeys, and humans [13]
1990	The implantation of an electrode in the motor cortex of a paralyzed patient [13]
1999	Trained rats using their brain signals to move a robotic water-dispensing arm [15]
2009	Honda, ATR and Shimadzu Jointly Developed Brain-Machine Interface Technology Enabling Control of a Robot by Human Thought Alone [16]
2009	Built a wireless implantable microelectronic device for transcutaneous transmission of cortical signals [9]
2015	Functional Electrical Stimulation(FES) and BMI technologies provide solutions for paralyzed individuals [14]
2017	Implanting tiny brain electrodes that can upload and download thoughts one day [10]
2017	"Neural lace" improves people's cognitive abilities [12]
2021	Implants in the brain and spinal cord seek to correct paralysis and cure Alzheimer's disease [11]

The BCI is classified into three namely Invasive, Semi invasive and Non-invasive. The invasive type of BCI can be applied to people with paralysis. It is implanted directly in the brain. The quality of the signal produced was high. The signal is most accurate. But the risk is, it can cause damage to the brain, leaves the brain exposed. The semi-invasive type of BCI devices is implanted inside the skull. It produces better resolution signals. Here the risk is less. Because the brain is not exposed, there is less risk to overall health. The non-invasive type of BCI is wearable and produces the signal. It disperses the electromagnetic waves generated by the neurons [7][8].

IV. APPLICATIONS OF BMI

Brain-Machine Interfaces can work seamlessly with IoT system to create Smart Environments like Houses, Transportation etc., this has got the attention of Marketing Giants to invest in BMI technologies. Brain-Machine Interfaces can help to find what kind of advertisements do people watch and their watch time, age demography and even their attention spans.

To overcome misuse or exploits, Cognitive Biometrics can be set up to provide security and authentication, thus working as an expansion of existing BMI technologies. As previously mentioned, Brain-Machine Interface can monitor attention spans and measure the lack of attention thus it can be used in the Education field to provide better and fulfilling education to students and stop malpractices during a test.

Even at this stage, the applications of BMI are overwhelming, with more research and proper implementation, it can become increasingly versatile and with improvement in the equipment used within BMI sensors, we can read and write more signals emitted by neurons. Thus, it is clear that the scope of the Brain-Machine Interface is only limited to our imagination and the domain we will be deploying BMI.

Some of the applications of BMI as of now include Direct Communication between the Human Brain and Computer interfaces. Better living standards and ease of control over IoT devices.

Domains where BMI can be deployed [7][8].

a. Medical

b. Bioengineering

c. Brain operated wheelchair

d. Games

e. Military

f. Manufacturing

g. Multimedia and Virtual Reality

h. Remote control of devices through the brain

It is clear that each of the mentioned domain has many applications for BMI and yet to be discovered applications of BMI in that particular Domain. We are focusing on Medical Benefits to help people who are crippled with genetic disorders, Autoimmune and other neural degenerative diseases. To enable them to interact with the physical world through prosthetics which are controlled by the thought of motion which occurs in our brain (several neurons' fires to animate the thought of motion) rather than the motion created by our muscles.

V. NEURALINK

Musk and its company "Neuralink" have published a paper since the launch of Neuralink, last year. The paper was submitted to the Journal of Medical Internet Research, in October. Musk uses this paper to describe the development of a robotic arm to insert hundreds of thin threads (which are about a tenth of the width of a human hair) into the brain, without damaging nearby neurons or brain tissue nearby. It has since been dubbed as the "sewing machine", it can insert around six threads per minute. Each thread composed of flexible plastics with 192 electrodes.

The company targeted Rodent Brain for early research purposes, Musk and Neuralink has set up two systems, A and B and tested them on rats. A can insert 1,500 electrodes while B can insert 3,000 electrodes. After setup, the rat can move freely without restriction with a USB-C slot sticking out of its head. In the same paper, it is acknowledged that some significant technological hurdles still exist and must be addressed to have a high-bandwidth device that can be employed in clinical trials [1].

Neuralink is under development but it has been approved by FDA after the demonstration by Elon Musk et al., on the 28th of August 2020 [3].

Neuralink claims to be different from other BMI technologies by developing far advanced brain implants compared to the current generation. Those advancements are thinner and lighter electrode threads of 4 – 6 μm in width, even thinner than a normal thinner. Another innovative idea is the introduction of a Robot to insert threads along with wireless hardware that operates those threads. An array of small and flexible electrode threads (as many as 3072 per array distributed across 96 threads) is also created by Musk and Neuralink. These threads are individually inserted by the neurosurgical robot with micro precision to avoid vascular damage and to keep special brain regions safe.

Six threads with a total of 192 electrodes can be inserted using the robot per minute. A small implantable device that contains custom chips that provide low power onboard amplification and digitization is where the electrode array is packaged. Along with a USB-C cable allowing data streaming of bandwidth from the device and recording of all channels simultaneously.

A device called "The Link", Bluetooth radio and a battery is connected to the implant through the skull. Software and system updates can be easily made with this configuration. Elon claims that compared to the other FDA approved Brain-Machine Interface, Neuralink is by far the most advanced and can be used to treat Parkinson's disease through Deep Brain Stimulation. Reading and Writing of thousands of more electrodes is possible if publicly approved [2].

VI. NEURALINK IN SMART HEALTHCARE

The patient's life is rescued when the Neuralink integrated into IoT. Over many types of research, Machine Learning and Deep Learning algorithms play a vital role in assisting the physician regarding disease forecasting from the patient's symptoms. But when Neuralink becomes Smart Neuralink in healthcare IoT application, the computer may receive huge data captured at every second. But it is a great challenge to analyze this stream of data. These data must be processed on the fly in IoT. Either online or incremental learning algorithm can be used to process this data [17]. Even though the smart Neuralink gives neuron's spike signals to the doctor's machine; the human's emotions also are recorded. There are much research work is going on in emotion recognition from speech signals [18]. To interpret or recognize the emotions from the recorded signals, good algorithms could be developed in future. Hence smart Neuralink integration will advance the concept of recognizing speech emotion from a human voice. The wearable clothes and wearable watches send signals about the wearer's health to their physician. Few wearables can be implanted into the body with the help of Neuralink. The wearable Link from Neuralink improves the cognitive function of disabled people. For non-disabled people, it connects the surrounding devices such as smart home, car, and other electronics devices [19].

CONCLUSION

In the future, Neuralink can help us understand our brain better by actually interacting with our neurons near larger bandwidth and data collection. We can use this data to discover new leads on various diseases like Parkinson's, Alzheimer's and dementia even have the potential to cure them or decrease their potential. By learning more about our brain, we can focus on expanding our memory or making our precious memories permanent. By doing extensive research and closely observing our brain and how it functions, we can create better AI systems and make them more creative instead of repetitive. Using AI-based algorithms we can predict what a person is thinking and use the data to allow people with disability to have prosthetic arms which feel and responses like a real arm. Potentially there might come a day whereof fusing soft prosthetics and bio-organics, we will be able to replace limbs easily and with great flexibility. Neuralink enabled smart devices also can predict stroke, heart attack and other ailments.

REFERENCES

[1] Shankland..S,"Elon Musk shows Neuralink brain implant working in a pig", CNET, 2020. www.cnet.com/news/elon-musk-shows-neuralink-brain-implant-working-in-a-pig/

[2] Sarah N. Abdulkader, Ayman Atia, Mostafa-Sami M. Mostafa, "Brain-computer interfacing: Applications and challenges", Egyptian Informatics Journal, Volume 16, Issue 2, Pages 213-230, 2015.

[3] Cate Lawrence, "Neuralink Reveals Their Brain-Machine Interface",IoTZone,Analysis,July22,2019.www.dzone.com/articles/neuralink-reveals-their-brain-machine-interface

[4] Musk E; Neuralink, "An Integrated Brain-Machine Interface Platform With Thousands of Channels", Journal of Medical Internet Research. 2019 Oct 31;21(10):e16194. doi: 10.2196/16194

[5] Alexandre Gonfalonieri, "A Beginner's Guide to Brain-computer Interface and Convolutional Neural Networks", Towards Data Science, November 25,2018. https://towardsdatascience.com/a-beginners-guide-to-brain-computer-interface-and-convolutional-neural-networks-9f35bd4af948

[6] Krucoff, Max O., Rahimpour, Shervin, Slutzky, Marc W. et al., "Enhancing Nervous System Recovery through Neurobiologics, Neural Interface Training, and Neurorehabilitation", Frontiers in Neuroscience, 10:584,2016. doi:10.3389/fnins.2016.00584

[7] H. S. AlZu'bi, N. S. Al-Zubi and W. Al-Nuaimy, "Toward Inexpensive and Practical Brain-Computer Interface," Developments in E-systems Engineering, Dubai, United Arab Emirates, pp. 98-101, 2011. doi: 10.1109/DeSE.2011.116.

[8] A. Vourvopoulos and F. Liarokapis, "Robot Navigation Using Brain-Computer Interfaces," IEEE 11th International Conference on Trust, Security and Privacy in Computing and Communications, Liverpool, UK, pp. 1785-1792, 2012. doi: 10.1109/TrustCom.2012.247

[9] Song YK, Borton DA, Park S, Patterson WR, Bull CW, Laiwalla F, Maslow J, Simeral JD, Donoghue JP, Nurmikko AV. "Active microelectronic neurosensory arrays for implantable brain communication interfaces", IEEE Trans Neural Syst Rehabil Eng., Aug;17(4):339-45, 2009. doi: 10.1109/TNSRE.2009.2024310.

[10] Rolfe Winkler, "Elon Musk Launches Neuralink to Connect Brains With Computers". Wall Street Journal. Archived from the original on May 5, 2017.

[11] Español, Entrepreneur en, "Neuralink Could Begin Testing Human Brain Implants This Year, Says Elon Musk", Entrepreneur. Retrieved February 6, 2021.

[12] Newitz, Annalee, "Elon Musk is setting up a company that will link brains and computers", Ars Technica, May 19, 2017. https://arstechnica.com/information-technology/2017/03/elonmusk-is-setting-up-a-company-that-will-link-brains-and-computers/

[13] Vidal, JJ, "Toward direct brain-computer communication", Annual Review of Biophysics and Bioengineering. 2:157–80, 1973. doi:10.1146/annurev.bb.02.060173.001105

[14] Ethier, C. & Miller, L. E, "Brain-controlled muscle stimulation for the restoration of motor function", Neurobiology of Disease, 83, 180–190, 2015. doi:10.1016/j.nbd.2014.10.014

[15] S. Ortiz, "Brain-computer interfaces: where human and machine meet" in Computer, vol. 40, no. 01, pp. 17-21, 2007. doi: 10.1109/MC.2007.11

[16] Honda, ATR and Shimadzu Jointly Develop Brain-Machine Interface Technology Enabling Control of a Robot by Human Thought Alone, March 31, 2009. https://hondanews.com/en-US/releases/honda-atr-and-shimadzu-jointly-develop-brain-machine-interface-technology-enabling-control-of-a-robot-by-human-thought-alone#:~:text=In%20May%202006%2C%20Honda%20and,special%20training%20of%20the%20user.

[17] Alex S.A. and Nayahi J.J.V, " Deep Incremental Learning for Big Data Stream Analytics", In: Pandian A., Senjyu T., Islam S., Wang H. (eds) Proceeding of the International Conference on Computer Networks, Big Data and IoT (ICCBI - 2018). ICCBI 2018. Lecture Notes on Data Engineering and Communications Technologies, Springer Cham, vol 31, 2020. https://doi.org/10.1007/978-3-030-24643-3_72

[18] Kumaran, U., Radha Rammohan, S., Nagarajan, S.M, and A.Prathik, "Fusion of mel and gammatone frequency cepstral coefficients for speech

emotion recognition using deep C-RNN", International Journal of Speech Technology, 2021. https://doi.org/10.1007/s10772-020-09792-x

[19] Kaygusuz, Pelçim. "Smart Wearables: About the Liability Question for Smart Wearables for Health Purposes." Available at SSRN 3701262, 2020.