# Neuralink: A Futuristic Exploration for Bridging Minds and Machine

**[1]Priyajit Pramanik, [2]Sayan Roy, [3]Anirban Bhar, [4]Suchismita Maiti**

[1,2] B. Tech student, [3]Assistant Professor, [4]Associate Professor
Department of Information Technology
Narula Institute of Technology
Kolkata, India.

***Abstract*- The lines that demarcate humans from machines are becoming increasingly hazy in today's rapidly advancing technological landscape. Humans are becoming more concerned that this abrupt rise in AI use would render humanity useless. Neuralink, a revolutionary firm in the field of neurotechnology that was established by Elon Musk, is at the vanguard of this current technological revolution. This research paper digs into Neuralink's ambitious objective to bridge the gap between minds and computers, investigating its potential consequences, ethical considerations, and the revolutionary impact it could have on society. Neuralink is a company that aims to bridge the gap between humans and robots. Brain-Machine Interface (BMI) technology and "Neural Lace" technology can both be used to do this. The study presents a complete review of Neuralink's invention and its potential to transform human cognition and communication by examining the science that lies behind the technology's surface.**

***Keywords*- AI, Neuralink, Brain-Machine Interface (BMI), Neural Lace.**

## I. INTRODUCTION

In a 1943 study on the potential function of neurons, neurologist Warren McCulloch and a young mathematician named Walter Pitts built a straightforward neural network with electrical circuits. John von Neumann proposed utilizing vacuum tubes and telegraph relays to implement basic neuron functions in 1957. In Today's time This implementation has come as outline of NEURALINK, a project by Elon Mask which have drawn a lot of attention since 2017. A business called Neuralink specializes in developing brain-machine interfaces (BMI) that are intended to be implanted in people's brains "to eventually improve memory and interface with computer systems." Elon Musk, a multibillionaire businessman, unveiled his pig Gertrude and the chip inserted in its brain on August 28, 2020. Neurological signals from Gertrude are retransmitted by the chip. A computer can forecast where each of Gertrude's objects will be at any time using this knowledge.

A brain-machine interface that is implanted into the top of the skull with electrodes penetrating approximately three millimeters into the cerebral cortex, the brain's outer layer. Neuralink, created in 2016 and backed by Elon Musk, aims to treat mental and physical health issues like depression, sleeplessness, addiction, and pain, as well as physical impairments like paralysis, blindness, hearing loss, and memory loss. Bluetooth connections to a smartphone app offer Neuralink's controlling software.

In order to create minimally displacive neural probes using a variety of biocompatible thin film materials, they have created a special process. These probes' primary substrate and dielectric material is polyimide, which is enclosed in a gold thin film trace. A "thread" area with electrode contacts and traces makes up each thin film array, and a "sensor" area is where the thin film connects to the custom chips needed for signal amplification and acquisition. These devices can be produced at high throughput using a wafer-level microfabrication process. A wafer is patterned with ten thin film devices, each with 3072 electrode contacts. There are a total of 32 separate electrodes spread across 48 or 96 threads in each array. A flip-chip bonding procedure is used to attach integrated chips to the contacts on the sensor area of the thin film. The strategy's major objective is to minimize brain tissue displacement by keeping the thread's cross-sectional area as small as possible. Stepper lithography and other microfabrication techniques are employed to produce the metal layer at submicron resolution, allowing for this while maintaining a high channel count.

In their arrays, they have designed and produced more than 20 different thread and electrode types. Reference electrodes are either placed on separate threads or on the same threads as the recording electrodes when designing probes. They have created threads with recording sites in a variety of geometries that range in width from 5 to 50 meters. Up to three layers of insulation and two layers of conductor are included in the thread's nominal 4-6 m thickness. About 20 mm is the average thread length. Before insertion, perylene-c is applied to the long, thin threads to create a film that the threads adhere to until the surgical robot pulls them out. This helps manage the long, thin threads. To facilitate needle threading, each thread is finished with a 16 x 50 m2 loop.

The small geometric surface areas of the individual gold electrode sites force us to use surface modifications to lower the impedance for electrophysiology and increase the effective charge-carrying capacity of the interface. They have used two of these treatments on electrically conductive polymers, poly-ethylenedioxythiophene doped with polystyrene sulfonate (PEDOT: PSS) and iridium oxide (IrO2). We measured the impedances for PEDOT:PSS and IrOx for benchtop testing to be 36.97 (SD 4.68) k for 257 electrodes and 56.46 (SD 7.10) k for 588 electrodes, respectively. Even though PEDOT:PSS has a lower impedance than IrOx, it has less established long-term stability and biocompatibility. To accommodate different kinds of conductive electrode materials and coatings, these techniques can be improved and expanded.

## II. LITERATURE REVIEW

The rationale behind the utilization of Neuralink is grounded in the fundamental neurophysiology of neurons. When neurons are subjected to a sufficient number of depolarizing impulses that surpass the depolarization threshold, they generate action potentials that propagate along their axons and result in the release of neurotransmitters that can either enhance or suppress subsequent signaling. The process under investigation is subjected to electrophysiological analysis, which results in the generation of a distinct pattern known as a "spike." This pattern can be detected and studied through the utilization of probes and microelectrode arrays [1]. The impact of damage on a neuron can result in changes to the effectiveness of depolarization, affecting either its frequency, amplitude, or both [2]. The efficacy of restoration in other areas and structures of the body surpasses that of neurons. Numerous in vitro studies have demonstrated the phenomenon of neuronal regeneration. However, in the context of the central nervous system, the capacity and location of in vivo neuronal regeneration are constrained. Specifically, this regenerative process is confined to specific regions, namely the olfactory sensory system, dentate gyrus of the hippocampus, and the forebrain subventricular zone [3-5]. Despite the identification of restorative potential, the ability to restore function from these locations remains severely restricted.

The potential for function regeneration in neurons of the peripheral nervous system has been enhanced due to the utilization of surgical procedures, such as autografts, which aim to enhance functional outcomes. Nevertheless, the occurrence of spontaneous recovery following the severing of peripheral nerves is exceedingly infrequent and frequently falls short of restoring the original level of functionality [6]. The development of Neuralink was driven by the recognition of a commonly held belief regarding the limited capacity for natural regeneration in both central and peripheral neurons, along with a desire to deepen our understanding of the underlying physiological mechanisms governing neuronal function.

The objective of restoring functionality through brain-machine interfaces (BMIs) is a common goal pursued not only by Neuralink but also by preceding technologies. Before the emergence of Neuralink, deep brain stimulation (DBS) has been a longstanding therapeutic approach for addressing movement disorders [7].

The consequences of deep brain stimulation (DBS) are influenced by several processes, with the most significant impacts observed on the electrical, neurochemical, and oscillatory activities of neurons that undergo firing [8]. The use of high-frequency electrical stimulation is employed for the purpose of regulating the voltage-gated sodium channels present in neural tissue, hence enabling control over the propagation of action potentials [9,10]. In conventional understanding, deep brain stimulation (DBS) has been thought to suppress neuronal activity. However, recent research has seen instances where DBS has led to heightened neural activity in the treatment of Parkinson's disease, indicating that the effects of DBS may vary depending on the specific tissue involved [11].

Neuralink exhibits two primary distinctions in comparison to the conventional deep brain stimulation (DBS) methodology: variations in fibre design and electrode quantity. The neuroprosthetic fibre design developed by Neuralink presents flexible and thin probes that incorporate a substantial number of electrodes within the fibres. This design feature enhances the compatibility of the probes with living tissue. The utilization of a robotic machine is necessary in order to enhance probe stiffness and guarantee precise placement within the brain, owing to the adaptable nature of its design. The expeditious installation of the Neuralink device involves the positioning of 96 probes, whereby each probe has 32 electrodes, resulting in a cumulative count of 3,072 electrodes distributed across the cerebral cortex [12]. In addition, the device is under constant surveillance by a Neuralink application-specific integrated circuit, enabling simultaneous monitoring of the patient's electrophysiological data. This stands in contrast to standard approaches that typically record data offline. Neuralink enhances the neuroprosthetic's efficacy by enabling a higher threshold of 0.2 Hz for accurate spike detection [12]. Neuralink aims to expand upon the existing framework of deep brain stimulation (DBS) and offer potential solutions for individuals with limited prospects for functional recovery.

The Neuralink device is comprised of a collection of 96 tiny and flexible electrode threads, each equipped with 32 distinct arrays. In all, each array consists of 3,072 electrodes [13,14]. Prior studies with deep brain stimulation (DBS) have demonstrated the feasibility of manipulating computer cursors, robotic limbs, and voice synthesizers through the utilization of a limited number of electrodes, typically not exceeding 256 [15]. The utilization of individually implanted threads containing many electrodes enables a significant amplification in channel count in comparison to previous brain-machine technology [15,16]. The utilization of a substantial quantity of electrodes facilitates enhanced precision, categorization, and comprehension of cerebral electrical activity, as well as an augmentation in the transmission of a substantial amount of data. This data can be subsequently processed, amplified, and transmitted to a machine for interpretation. Alternatively, it can be employed to convey signals to the brain, thereby assisting in the management of various other neurological disorders [13,14,15]. Musk and his team have conducted experiments with several metal and polymer materials, and have concluded that a biocompatible polyimide material, when used in conjunction with a gold thin film trace, represents the most optimal choice for the threads. Every individual thread is equipped with an electrode contact, traces, and a sensor region, which provide communication with the custom chip for the purpose of signal amplification. The array threads consist of a dual layer of conductive material enveloped by three layers of insulating material. These threads have a diameter ranging from 4 to 6 µm and a length of 20 mm. At their termination, they form a loop with dimensions of 16 × 50 µm2, which facilitates their insertion. Threads are placed on a perylene-c film until they are prepared for insertion, owing to their significantly small size [13]. The utilization of flexible polymer threads, as opposed to conventional rigid metals, offers several advantages in terms of immune response reduction, enhanced biocompatibility, and the ability to accommodate brain movement and circumvent brain vasculature. The utilization of several pliable threads presents a constraint in the context of surgical implantation. The diminutive dimensions and pliability of the individual threads pose challenges in terms of their implantation, rendering the operation arduous and time-consuming. In order to surmount this challenge, Neuralink has developed a surgical robot that exhibits the ability to meticulously and safely insert each thread separately, while concurrently evading surface vasculature and accurately targeting specific regions within the brain. The surgical robot achieves this objective by employing picture stacking techniques from six distinct light modules that possess the capability to illuminate at wavelengths of 405 nm, 525 nm, and 650 nm, in conjunction with stereoscopic cameras. Various light illuminations provide enhanced visualization of the intricate thread and cortex structures within the brain, enabling the robot to effectively illuminate and identify the thread loop for needle threading purposes, as well as ensuring precise insertion of the thread into the cortical surface. The robot employs predetermined insertion sites, depth tracking, and skull landmarks to effectively and accurately avoid brain vasculature throughout the insertion process. The robot was tested on 19 rat models, and the results showed an average insertion success rate of 87.1% [13].

The task of receiving and transcribing information from over 3,000 electrodes is an additional challenge. The Neuralink device necessitates the ability to capture, convert into digital format, and enhance minute neural impulses measuring less than 10 microvolts root mean square (µVRMS). Simultaneously, it must effectively eliminate extraneous noise outside the desired frequency range, and transmit these signals in real-time for immediate analysis, all while maintaining a compact design and operating with minimal power consumption. The Neuralink device is comprised of 256 amplifiers that may be programmed individually, on-chip digital converters, and peripheral control circuitry for the serialization of the digitized outputs. Neuralink employs a proprietary web-based spike-detection program for the purpose of deciphering and presenting the signals. The signals are visually shown on a graph, where each row of the graph corresponds to a specific electrode site located on the thread [13].

In a scholarly article released in 2019, Elon Musk provided a comprehensive account of Neuralink's two platforms that are intended to specifically address the brain for the purpose of neuroprosthetic applications [12,14]. The company has developed two distinct configurations, namely "System A" and "System B," which exhibit variations across multiple factors. According to the report, System A was comprised of a 1,535-channel system that had superior performance parameters compared to System B, which had 3,072 channels. The first testing of both systems involved the utilization of male Long-Evans rats, allowing them unfettered movement. According to Musk, System A demonstrated the capability to concurrently record 1,344 channels out of a total of 1,535, whilst System B worked at a complete recording capacity of 100%. In addition, a threshold value greater than 0.35 Hz was employed to capture and record spiking units. Using System A, a total of 40 out of 44 device insertions were deemed effective, resulting in spikes occurring in about 43.4% of the channels. In previous studies, the experimental results of System A indicated spike yields reaching a maximum of 70% [12].

The forthcoming human trials will play a crucial role in the investigation and substantiation of the neuroprostheses provided by Neuralink. The completion of human trials by Neuralink in 2021 is a significant objective. However, it is important to thoroughly investigate the safety and biocompatibility of the human brain in order to establish the efficacy of the Neuralink device in modulating and regulating human neuronal impulses.

The concept of Neuralink elicits numerous inquiries regarding its feasibility and effectiveness within the realm of clinical application. The successful implementation of the Neuralink device necessitates the involvement of both a Neuralink robot and a skilled neurosurgeon. The neurosurgeon must undergo extensive training to ensure proficiency and ensure the safety and comfort of the procedure. The primary objective of the minute size of the electrode is to enable access to anatomically protected neurons while minimizing the risk of damage to nearby blood vessels. The sluggish integration of real robotic systems into the field of neurosurgery can be attributed to the necessity of training with these devices. This phenomenon is also observed in the case of Neuralink, which is not exempt from this trend. In contrast, co-robots, commonly referred to as "cobots," are being consistently included into neurosurgical practice [17].

The effectiveness of this gadget is further constrained by the particular diseases exhibited by patients. The utilization of a DEKA arm and brain-computer interface (BCI) has demonstrated the restoration of motor function in individuals with quadriplegia by converting neural activity into control signals for manipulating the DEKA arm [18]. The potential challenges in restoring motor function with Neuralink or other Brain-Computer Interface (BCI) systems may arise when the injury to the motor cortex or spinal cord is extensive. Additional research and exploration of the relationship between brain-computer interfaces (BCIs) and the regeneration of neurons within living organisms is necessary.

One possible avenue for the integration of Neuralink technology into the field of neurosurgery involves its application in the categorization and prevention of brain tumor recurrence. In a study conducted by Hatcher et al., the researchers measured the degree of hyperexcitability in neurons adjacent to glioblastoma multiforme (GBM) tumors in mice, which is known to cause recurrent seizures, a prevalent symptom in GBM patients [14]. Following the surgical removal of the tumor, the placement of Neuralink threads at the tumor site and its surrounding regions could enable the identification of heightened neuronal excitability, thereby indicating the necessity for additional resection or more potent chemotherapeutic interventions. The utilization of this data has the potential to decrease the duration required for identifying the reappearance and spread of cancer in individuals diagnosed with glioblastoma and other infiltrative malignancies. Furthermore, it may also contribute to an improvement in the overall survival rates of these patients. Although there exist numerous concerns regarding Neuralink, its potential for integration into future neurosurgical practice holds promise for enhancing patient outcomes.

## III. NEUROTECHNOLOGY AND BRAIN-COMPUTER INTERFACES (BCIS)

At the intersection of neuroscience, engineering, and computer science, neurotechnology and Brain-Computer Interfaces (BCIs) are swiftly evolving fields. Various aspects of healthcare, communication, and human-computer interaction have the potential to be revolutionized by these technologies. Here is a summary of these ideas:

### A. Neurotechnology:

Neurotechnology is the application of techniques to comprehend, repair, replace, enhance, or otherwise affect the structure and function of the nervous system. It includes a vast array of technologies and techniques, such as:

***Neuroimaging:*** Methods such as fMRI (functional magnetic resonance imaging) and EEG (electroencephalography) enable researchers to visualize brain activity and investigate neural processes.

***Neurostimulation:*** Methods such as TMS (transcranial magnetic stimulation) and DBS (deep brain stimulation) use electrical or magnetic fields to modulate neural activity. These techniques are used to treat a variety of neurological and psychiatric conditions.

***Neuropharmacology:*** The use of medications to influence the nervous system, typically to treat epilepsy, depression, and ADHD.

### B. Brain-Computer Interfaces (BCIs):

BCIs are a subset of neurotechnology that establish a direct communication pathway between the brain and an external device, such as a computer or a mechanized system. BCIs can be either invasive (implanted directly into the brain) or non-invasive (external, frequently utilizing EEG). Key BCI features include:

***Invasive BCIs:*** Surgically implanting electrodes directly into the brain tissue constitutes invasive BCIs. They are frequently used in research and have demonstrated promising results in assisting paralyzed individuals to regain control of their extremities or communicate.

***Non-invasive BCIs:*** These BCIs, which frequently utilize EEG, detect brainwaves through electrodes inserted on the scalp. They are less precise than invasive techniques, but have a wider range of applications, such as neurofeedback, assistive technology, and gaming.

## IV. NEUROETHICS AND ETHICAL IMPLICATIONS

Neuroethics is the study of the ethical, legal, and social consequences of neuroscience and neurotechnology. It addresses questions and concerns associated with the utilisation of advances in neuroscience research and their applications in fields such as medicine, neurology, psychology, and beyond. In the field of neuroethics, several major ethical implications arise, including:

### A. Privacy and Brain Data:

Problem: The advancement of neuroimaging technologies raises privacy concerns regarding the thoughts, emotions, and brain activity of individuals.

Implication: Ethical guidelines are required to ensure that brain data is not misappropriated, accessed without consent, or used for discriminatory purposes.

### B. *Enhancement and Human Nature:*

Problem: Neurotechnologies can improve cognitive and physical abilities, which raises concerns about what it means to be human and the fairness of such enhancements.

Implication: Society must contend with defining the limits of enhancement, taking individual autonomy and social equality into account.

### C. *Neurobiological Basis of Morality:*

Problem: Discoveries about the neural basis of morality challenge traditional philosophical and religious beliefs about right and evil.

Implication: Ethical frameworks must be revised to integrate neuroscientific findings to ensure a nuanced comprehension of moral decision-making.

### D. *Brain-Computer Interfaces (BCIs):*

Problem: BCIs raise ethical concerns regarding the integration of human brains and machinery, as well as the potential impact on identity and agency.

Implication: To protect individuals from potential misuse, ensure informed consent, and prevent unauthorised access, safeguards and regulations are required.

### E. *Neuroscience in the Legal System:*

Problem: Neuroscientific findings, such as brain scans, are increasingly being used in legal contexts, raising concerns about the reliability and morality of such evidence.

Implication: Legal standards and protocols must be established to assure the responsible application of neuroscience in the courtroom, addressing issues of reliability, admissibility, and potential biases.

### F. *Neurodiversity and Social Stigma:*

Problem: Neuroscience advancements challenge societal perceptions of neurological and psychiatric disorders, influencing how people with these disorders are perceived and treated.

Implication: The implication is that society must promote neurodiversity by nurturing acceptance and accommodation for individuals with diverse neurological profiles and combating stigmas associated with mental health and neurological disorders.

### G. *Dual-Use Dilemmas:*

Problem: Neurotechnology created for beneficial purposes may be abused for detrimental or malicious purposes (dual-use dilemma).

Implication: Ethical oversight and responsible innovation are necessary to reduce the possibility that neuroscientific advances will be used for detrimental purposes, such as mind control or surveillance.

To address these ethical implications, neuroscientists, ethicists, policymakers, and society as a whole must collaborate. To ensure that neuroscientific research and its applications adhere to moral principles, human rights, and societal values, ethical frameworks and guidelines should be continuously revised.

## V. NEURALINK-POSITIVE AND NEGATIVE ASPECTS

Few positive aspects of Neyralink may be summarized as:

People with disabilities will enjoy a higher quality of life due to Neuralink. It will restore body control to paralyzed patients. It will give the blind their sight back. And it will enable deaf individuals to hear again.

With the aid of this technology, humans will be able to effortlessly interact with machines without the need for external devices such as touch screens and keyboards. In other terms, machines can be operated without the use of hands or voices. Through a neural implant in their brain, they can readily access their thoughts.

Neuralink technology could make us smarter by directly connecting our brains to computers, granting us instantaneous access to a vast quantity of information. Recording memories and listening to them later may also aid in memory recall. It could also prevent people from losing their memories as they age by enabling them to upload their memories to an artificial intelligence system stored on a server in the cloud, where they would never be lost.

Few negative aspects of Neyralink may be summarized as:

One of the primary concerns regarding Neuralink is that it may cause brain tissue injury. Even a minor injury can result in permanent harm or death to the human brain, which is extremely sensitive. If implanted improperly, Neuralink can induce infections and inflammation in the brain.

Neuralink's ability to read thoughts but not record memories. which can invade one's privacy, a serious concern. If the device is implanted in your brain, anyone with access to it will be able to read your memories and thoughts. It could also be utilized by governments or private corporations to monitor the thoughts and actions of individuals without their consent or knowledge.

There is a chance that BCIs will fail at some point in the future and there will be no way to rectify them. The insertion of electrodes into brain tissue has the potential to induce brain damage. The implants may also cause scarring at the implantation site.

## VI. FUTURE DIRECTION AND CONCLUSION

Significant leaps forward could be possible in areas such as human-machine interface and medical care if Neuralink technology is developed further in the future. The following are some conceivable trajectories that Neuralink's effect could take:

By accurately manipulating neuronal activity, the technology developed by Neuralink has the potential to assist in the treatment of neurological conditions such as epilepsy, depression, and Parkinson's disease.

We are able to link to any machine that can read inputs from our brains by using an interface that is either referred to as a brain-machine interface (BMI) or a brain-to-machine interface (B2M). Because we only use two of our thumbs to input data into computers or smartphones, we have a very low bandwidth rate, which means that we need a high bandwidth rate for this. However, we only have a very low bandwidth rate. We will not be able to obtain the same bandwidth by utilising images, movies, and audios as we will be able to do by transmitting information straight from the brain to the machine.

Neuralink's goal is to create brain-machine interfaces (BMIs) that will enable direct communication between the human brain and other technologies. Individuals who are paralyzed could profit from this since it would give them the ability to manipulate prosthetic limbs or interact with computers.

There will be substantial ethical and privacy considerations associated with the use of BMIs, as is the case with any other type of advanced technology. This will be an important topic of discussion within the larger society.

The ease with which and the cost at which the Neuralink technology may be made available to a greater number of individuals will have a significant impact on the future impact of the technology.

Neuralink's goal is to build brain-computer interfaces, or BCIs for short, so that individuals can interact telepathically across great distances without the assistance of technology such as mobile phones or personal computers.

It is one of the many benefits of this technology because it can help paraplegics regain their movement through the use of robotic prostheses that are controlled by electrical signals originating from the patients' brains. This is only one of the many advantages of this technology. Even though the idea is still in its preliminary phases, there has already been interest shown in it from a number of investors as well as potential clients.

If Neuralink is successful in developing this technology, it will have a significant impact not only on our own lives but also on the lives of everyone else in the world. On the other hand, there are a number of potential dangers associated with this endeavour, all of which need to be thoroughly evaluated before any action is done.

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