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Mind Over Machine: Elon Musk's Neuralink Brain Chip

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Abstract- As the days pass by, we come across new and latest inventions that utilize Artificial Intelligence to enhance our device usage. Neuralink is a neurotechnology venture founded by Elon Musk, focusing on the development of implantable brain-machine interface (BMI) systems. The core device is a coin-sized chip, known as the Link, which contains ultra- thin electrode threads designed to record and stimulate neural activity. These threads are surgically implanted into specific regions of the cerebral cortex using a high-precision surgical robot. The device wirelessly transmits neural signals to an external application, enabling real-time interaction between the brain and digital devices. Neuralink's primary goal is to assist individuals with neurological disorders, such as paralysis, ALS, or spinal cord injuries, by enabling direct neural control of computers and prosthetics. Long-term objectives include enhancing cognitive function, treating neurodegenerative diseases, and facilitating human-AI symbiosis.

Keywords: Artificial Intelligence (AI), Neuralink, Elon Musk, Neurotechnology, Brain-machine interface (BMI).

I. INTRODUCTION

Neuralink is a neurotechnology company founded by Elon Musk with the mission of developing advanced brain- machine interface (BMI) systems that establish a direct link between the human brain and external digital devices. On 16th July 2019, a white paper was published under the name, "ELON MUSK AND NEURALINK" which told about what the company was up to and how it was possible to create a general symbiosis between man and machine or artificial intelligence (AI). Elon Musk at the launch event of Neuralink said that the company aims to " understand and treat brain disorders," along with " preserving and enhancing our brain," and "creating a well-aligned future."

NEURALINK

The core of this innovation lies in the Neuralink brain chip, also known as the Link—a compact, implantable device designed to record and stimulate neural activity with high precision. Neuralink's short-term goals include assisting individuals with paralysis, spinal cord injuries, and communication impairments, while long-term objectives envision cognitive enhancement, neuroprosthetics, and seamless integration with artificial intelligence.

What is Neuralink, and how does it work?

The project represents a convergence of neuroscience, biomedical engineering, and digital technology, offering transformative potential for both clinical therapy and human–machine interaction. Neuralink's work is driven by the convergence of neuroscience, robotics, biomedical engineering, and artificial intelligence.

At the heart of Neuralink's technology is the Link, a compact, coin-sized neural implant designed to be surgically embedded in the skull. This device contains custom microelectronics and is connected to the brain via ultra-thin, flexible electrode threads, each thinner than a human hair. To address the complexity and precision required for implantation, Neuralink has developed a high-precision robotic surgical system capable of inserting these threads into the brain while avoiding blood vessels, thereby minimizing trauma and improving accuracy.

● **The Brain Chip:**

The link is the central component of Neuralink's brain-machine interface system. It is a compact, biocompatible neural implant designed to be embedded flush within the skull. The device is shaped like a coin (approximately 23 mm in diameter and 8 mm thick) and replaces a small portion of the skull to sit securely and unobtrusively beneath the scalp. The Link connects to the brain via up to 1,024 ultra-thin electrode threads, each embedded with multiple microelectrodes.

The Link includes custom analog front-end (AFE) chips that amplify and digitize the recorded neural signals. Each channel processes the signal in real-time to minimize noise and ensure accurate detection of neural activity. These signals are then passed through digital signal processors (DSPs) that compress and encode the data before transmission.

The device is designed to operate with low power consumption to avoid heating brain tissue and to maximize battery life.

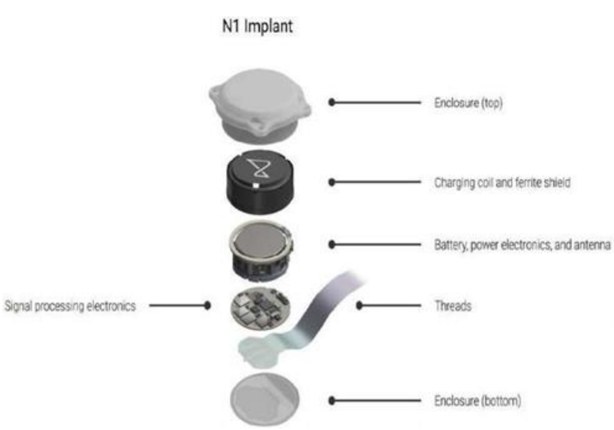

Figure1: BRAIN CHIP (LINK)

● **Electrode Threads:**

These threads are inserted into specific regions of the cerebral cortex, primarily the motor and somatosensory areas, depending on the intended application. The electrodes are designed to record action potentials (spikes) from individual or small groups of neurons with high spatial and temporal resolution. The flexible nature of the threads reduces the risk of scarring and inflammation compared to rigid implants. The electrode threads play a critical role in Neuralink's functionality. Each thread contains multiple electrodes that penetrate the cerebral cortex to detect the electrical impulses generated by neurons. These impulses are captured as raw neural data, which the implant's onboard electronics digitize and prepare for transmission. The system is capable of sampling thousands of neural signals simultaneously, enabling fine-grained monitoring of brain activity, and is also capable of both recording neural activity and stimulating neurons. These threads are significantly thinner than human hair, allowing them to interact with brain tissue with minimal damage and high biocompatibility.

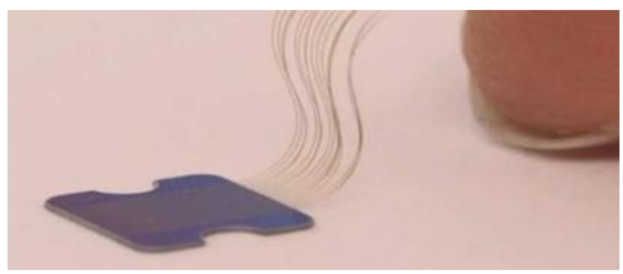

Figure: ELECTRODE THREADS

● Robotic Surgery:

The robotic surgical system developed by Neuralink represents a major technological leap in neurosurgery. Robotic surgical system, designed to implant the ultra-thin, flexible electrode threads into the human brain with micron-level precision. The primary function of Neuralink's robotic system is to accurately insert ultra-fine electrode threads (4 to 6 µm thick) into the brain's cortex. Traditional manual surgery cannot achieve the required precision or consistency, especially when placing hundreds or thousands of threads. The robot overcomes this limitation by using advanced optical imaging, computer vision, and precision actuation systems to

detect ideal insertion sites and deploy the electrodes without damaging brain tissue or blood vessels.
It includes :

- A Needle-like inserter designed to grasp and insert the individual electrode threads one at a time.
- An automatic guidance system that maps out the cortical surface and detects blood vessels to avoid hemorrhaging.
- A motion stabilization that compensates for brain movement caused by the patient's heartbeat or respiration, ensuring highly accurate placement.

The robot is capable of inserting up to six threads (192 electrodes) per minute. It can target specific brain regions with sub-millimeter precision, minimizing trauma and inflammation. The robotic surgery is designed to be minimally invasive and eventually suitable for outpatient settings. Safety is central to Neuralink's surgical system. The robot includes numerous fail-safes, including error detection algorithms, force sensors, and real-time monitoring of insertion depth and resistance.

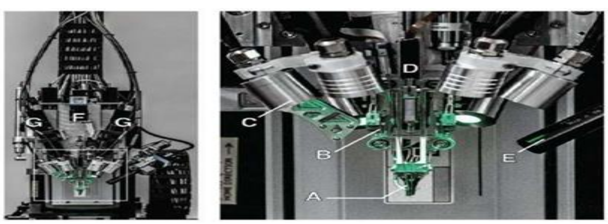

Figure2: ROBOTIC SURGERY

- Wireless communication :

A major feature of the Link is its wireless data transmission capability. It uses Bluetooth Low Energy (BLE) or similar protocols to stream neural data to external devices such as smartphones or computers. This wireless interface allows the user to control applications, cursors, keyboards, or robotic systems using only neural intent. Future iterations may include higher-bandwidth RF systems for faster and more complex data exchange. Once the neural signals are transmitted, external software equipped with machine learning algorithms decodes the data into actionable commands. This real-time brain–device communication can enable users to control computers, mobile devices, or even prosthetic limbs through thought alone. The wireless architecture eliminates the need for transdermal connectors, reducing infection risk and improving comfort.

- Power supply and changing :

The Link is powered by a rechargeable lithium-ion battery. It is wirelessly charged via inductive coupling using a specially designed external charging device placed near the scalp. The charging system is designed to be safe and user-friendly, allowing for regular recharging without the need for surgical intervention or wired connections. The entire implant is encapsulated in biocompatible materials, such as medical-grade polymers or ceramics, to ensure long-term stability and to prevent immune rejection. The device is hermetically sealed to protect internal electronics from the body's fluids. Neuralink has also incorporated safety features such as overheat protection, current limiting, and fault detection to meet medical device regulations and ensure user safety.

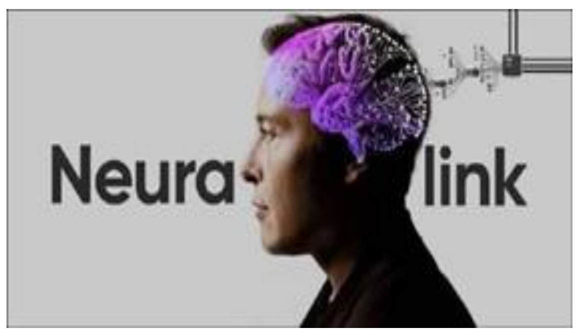

Figure3: IMPLANTATION

II. LITERATURE REVIEW

The development of brain–computer interfaces (BCIs) has been a subject of extensive research over the past few decades, primarily aimed at restoring sensory and motor functions for individuals with neurological impairments. Early BCI systems focused on electroencephalography (EEG)-based non-invasive methods, which, although safe, suffered from low spatial resolution and limited signal fidelity. To address these challenges, invasive interfaces such as electrocorticography (ECoG) and intracortical microelectrode arrays were introduced, offering higher signal precision but with increased surgical complexity and risk of immune response. From a technological perspective, Neuralink’s literature emphasizes several key innovations: robot-assisted implantation, custom low-power chips for signal processing, and wireless inductive charging. Neuralink represents a frontier in BCI research, combining advances in neuroscience, robotics, and materials science.

III. TEST SUBJECTS

Neuralink tested its brain chip technology on animals, most notably monkeys and pigs, to demonstrate the device’s
capabilities and safety. These preclinical tests were essential to gain FDA approval for human trials.

- **Monkey Trials**

In the year 2021, A Macaque monkey named Pager played the video game Pong using only its brain. The monkey had two Neuralink chips implanted—one in each hemisphere of its motor cortex. Initially, Pager used a joystick while Neuralink recorded neural activity associated with hand movements. After training, the joystick was removed, and the chip enabled the monkey to control the game purely with thought. His experiment demonstrated:

- Real-time brain-to-computer communication
- The ability to decode intended movement
- The chip’s wireless signal transmission and durability

This success helped validate the concept that the brain chip could restore control functions for paralyzed humans.

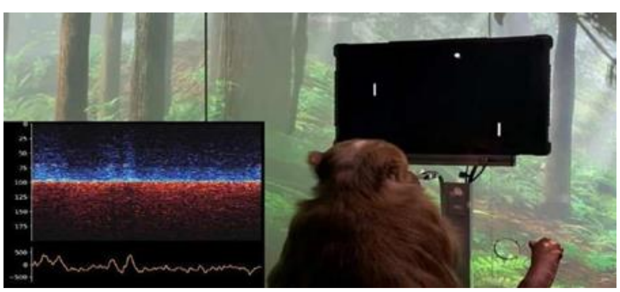

Figure4:MONKEY TRIAL

- **Pig Trials**

In August 2020, Neuralink introduced Gertrude, a pig with a Neuralink chip implanted in her brain. The demonstration focused on how the chip could record real-time neural activity from Gertrude’s snout as she interacted with her environment. The system visualized spikes on a screen each time her nose touched something, showcasing how the chip could monitor sensory inputs and potentially output movement or touch feedback in the future.
Pigs were chosen because their brain structure and size are somewhat comparable to humans for certain neurophysiological experiments. These trials helped: Validate the surgical robot’s precisionConfirm the safety and stability of the implants Demonstrate how sensory input is detected in real time.

Human trials

- Noland Arbaugh

In January 2024, Noland Arbaugh became the first human to receive Neuralink's N1 implant. A 29-year-old quadriplegic from Arizona, Arbaugh suffered a spinal cord injury in 2016 that left him paralyzed from the shoulders down. Post-implantation, he demonstrated the ability to control a computer cursor using only his thoughts, allowing him to engage in activities such as browsing the internet, playing video games, and composing messages. Despite initial challenges, including some electrode threads retracting due to brain movement, software optimizations restored significant functionality. Arbaugh's experience underscores the potential of BCI technology to restore autonomy to individuals with severe mobility impairments.

Figure5: HUMAN TRAIL

"Alex" (Pseudonym)
The second participant, referred to as "Alex," received the implant in August 2024. Alex, who has a spinal cord injury, utilized the device to play video games and design 3D objects. Unlike the first implantation, adjustments were made to reduce brain motion and place the implant closer to the brain's surface, mitigating thread retraction issues. Alex reported no complications post-surgery and expressed that the implant significantly contributed to regaining independence.

Brad Smith
In May 2025, Brad Smith, a nonverbal individual with amyotrophic lateral sclerosis (ALS), became the third person to receive the Neuralink implant. Smith utilized the device to edit and narrate a video using only his brain signals. The implant enabled him to control a computer cursor by imagining movements like jaw clenching and tongue motion.

Additionally, synthetic AI reconstructed Smith's voice from pre-ALS recordings, allowing him to narrate his video. This development highlights the technology's potential to restore communication abilities in individuals with severe neurological conditions.

IV. APPLICATIONS

- **Medical and Therapeutic Applications**

Restores movement control for paralyzed individuals and helps to treat neurological disorders like Parkinson's and
epilepsy.

- **Brain–Computer Interface (BCI) Applications**

Enables direct brain control of computers and smart devices.Supports brain activity monitoring for mental health treatment.

- **Cognitive and Educational Enhancement (Long-term Vision)**

Aims to enhance memory and cognitive functions in the future.Aids neuroscience research through high-resolution brain data.

- **Human–Artificial Intelligence (AI) Integration**
  To create a high-bandwidth interface to link human intelligence with AI, reducing the risk of humans being outpaced or outcompeted by machines.

- **Research and Neuroscience**

Neuralink can provide researchers with valuable insights into how the brain works, aiding discoveries in neuroscience

V. CHALLENGES

- **Electrode Thread Retraction**

In human trials, some electrode threads retracted from brain tissue due to movement, leading to a temporary loss of signal quality—this required software recalibration to restore performance.

- **Power Supply and Miniaturization**

Developing a chip that is small, wireless, fully implantable, and still powerful enough to process and transmit brain signals is a major engineering challenge.

- **Public Perception and Trust**

The concept of brain implants is still met with or fear by the public, which can slow adoption and funding unless transparency and safety are consistently demonstrated.

- **Microscale Robotic Surgery**

Implanting ultra-thin threads (thinner than a human hair) precisely into target cortical areas requires a custom-built surgical robot with micron-level accuracy and minimal trauma.

- **Ethical and Privacy Considerations Brain–** computer interfaces raise concerns about user consent, mental autonomy, and data protection, especially as decoding becomes more precise.

- **Biocompatibility and Safety**

Ensuring that the chip and its ultra-thin electrodes can remain safely implanted in the brain for long periods without causing inflammation, scarring, or rejection has been a major problem.

VI. FUTURE DIRECTION

Human–AI Symbiosis
Elon Musk envisions Neuralink enabling a high-bandwidth link between the human brain and artificial intelligence, ensuring humans remain competitive in an AI-driven world.

Wireless Cloud Connectivity
Future chips may integrate with cloud systems to store or access information directly from the brain, possibly enabling real-time learning or communication with external systems.

Advanced Medical Applications
Neuralink aims to expand beyond motor restoration to treat a wider range of neurological conditions, such as
Alzheimer's disease, stroke rehabilitation, chronic pain, epilepsy, and depression, through targeted brain stimulation.

Ethical AI-Integrated Neurotechnology
Future directions also focus on creating secure, ethical frameworks for data privacy, brain autonomy, and safe use of neural augmentation, particularly as AI integration grows.
Educational and Skill Enhancement Platforms
Neuralink might be used to accelerate learning or directly interface with educational software, offering brain-based tutoring or cognitive training systems.

CEO OF SpaceX

VII. PROS AND CONS

- **PROS :**
- High-resolution data capture.
- Fully wireless with compact design.
- Ambitious future goals (memory storage, telepathy, etc.). Focus on scalable robotic implantation.
- Medical applications that can help restore movement in paralyzed patients.
- Allows users to control computers, phones, or prosthetics using only their thoughts.

- **CONS:**

Highly invasive and risky procedure. Still in early human testing.
Ethical concerns (privacy, brain control). Competition already has proven medical use cases.
Requires brain surgery, with risks of infection, bleeding, or brain damage. The possibility of brain data being hacked or misused.

VIII. OVERVIEW

- **Neuralink Brain Chip:** Overview

Developer: Neuralink Corporation, co-founded by Elon Musk.

- **Purpose:** To create a high-bandwidth, implantable brain–machine interface (BMI) that connects the human brain to computers.
- **Design:** A coin-sized chip implanted in the skull, with ultra-thin threads (electrodes) inserted into the brain. Communication: Reads brain signals and transmits data wirelessly

Neuralink is a neurotechnology company founded by Elon Musk in 2016 with the mission to develop advanced brain-machine interfaces (BMIs). The core technology involves implanting flexible, thread-like electrodes into the brain to record neural activity and stimulate brain regions. These electrodes are
connected to a custom-designed chip capable of wirelessly transmitting data to external devices. The short-term goal of Neuralink is to help people with severe neurological conditions, such as spinal cord injuries or ALS, regain functions like movement or communication. In the long term, the company envisions a future where humans can merge with artificial intelligence to enhance cognitive abilities and prevent obsolescence in an AI-driven world.
Neuralink has demonstrated success in animal trials and received FDA approval for its first human trials in 2023. While the technology shows great promise,

it also brings challenges related to ethics, safety, accessibility, and long- term societal implications.

IX. CONCLUSION

Neuralink stands out for its technological ambition, high data bandwidth, and futuristic goals. However, competitors like Blackrock Neurotech and Synchron are currently more focused on immediate clinical applications and have already seen real-world use. While Neuralink could revolutionize human-computer interaction in the future, its long-term safety, ethics, and practicality remain under observation. Neuralink represents a groundbreaking step in the evolution of brain-computer interfaces, with the potential to revolutionize medicine, communication, and human-computer interaction. It holds great promise for treating neurological conditions and enabling people with disabilities to lead more independent lives. However, the technology is still in its early stages and comes with significant ethical, medical, and social concerns. The future of Neuralink will depend on careful scientific validation, regulatory oversight, and public discourse. If developed responsibly, it could unlock new frontiers in human capability—yet it also demands caution to avoid unintended consequences.

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