1. INTRODUCTION

In 1943, a neurologist Warren McCulloch and a young mathematician Walter Pitts wrote a paper on how neurons might work; they modelled a simple neural network with electrical circuits. In 1957, John von Neumann suggested simple neuron functions by using telegraph relays and vacuum tubes. Recently, the studies related to neural networks have taken a sudden leap and it is being used to heal a person's brainly disorders. Neuralink has gone out of the bounds of current studies in neural network and has started to not just cure the patients but also connect them to digital devices and help them use these devices without the need of using any of their body parts.

Brain Machine interfaces (BMIs) have the potential to help people with a wide range of clinical disorders. For example, researchers have demonstrated human neuroprosthetic control of computer cursors, robotic limbs, and speech synthesizers using no more than 256 electrodes. While these successes suggest that high fidelity information transfer between brains and machines is possible, development of BMI has been critically limited by the inability to record from large numbers of neurons. Noninvasive approaches can record the average of millions of neurons through the skull, but this signal is distorted and nonspecific. Invasive electrodes placed on the surface of the cortex can record useful signals, but they are limited in that they average the activity of thousands of neurons and cannot record signals deep in the brain. Most BMI's have used invasive techniques because the most precise readout of neural representations requires recording single action potentials from neurons in distributed, functionally-linked ensembles.

Microelectrodes are the gold-standard technology for recording action potentials, but there has not been a clinically-translatable microelectrode technology for large-scale recordings. This would require a system with material properties that provide high biocompatibility, safety, and longevity. Moreover, this device would also need a practical surgical approach and high-density, low-power electronics to ultimately facilitate fully-implanted wireless operation.

Most devices for long-term neural recording are arrays of electrodes made from rigid metals or semiconductor. While rigid metal arrays facilitate penetrating the brain, the size, Young's modulus and bending stiffness mismatches between stiff probes and brain tissue can drive immune responses that limit the function and longevity of these devices. Furthermore, the fixed geometry of these arrays constrains the populations of neurons that can be accessed, especially due to the presence of vasculature.

An alternative approach is to use thin, flexible multi-electrode polymer probes]. The smaller size and increased flexibility of these probes should offer greater biocompatibility. However, a drawback of this approach is that thin polymer probes are not stiff enough to directly insert into the brain; their insertion must be facilitated by stiffeners injection or other approach, all of which are quite slow. To satisfy the functional requirements for a high-bandwidth BMI, while taking advantage of the properties of thin-film devices, they developed a robotic approach, where large numbers of fine and flexible polymer probes are efficiently and independently inserted across multiple brain regions.

Here, they report Neuralink's progress towards a flexible, scalable BMI that increases channel count by an order of magnitude over prior work. Our system has three main components: ultra-fine polymer probes of this report), a neurosurgical robot, and custom high-density electronics. They demonstrate the rapid implantation of 96 polymer threads, each thread with 32 electrodes, in a $(4 \times 7)\ mm^2$ area of brain for a total of 3,072 electrodes. This system serves as a state-of-the-art research platform and a first prototype towards a fully implantable human BMI. It's going to be important from an existential threat perspective to achieve a good AI symbiosis.

2. LITERATURE SURVEY

2.1 History

Neuralink was founded in 2016 by Elon Musk, Ben Rapoport, Dongjin Seo, Max Hodak, Paul Merolla, Philip Sabes, Tim Gardner, Tim Hanson, and Vanessa Tolosa.

In April 2017, the blog wait but why, reported that the company was aiming to make devices to treat serious brain diseases in the short-term, with the eventual goal of human enhancement, sometimes called transhumanism. Musk said his interest in the idea partly stemmed from the science fiction concept of "neural lace" in the fictional universe in The Culture, a series of 10 novels by Iain M Banks.

Musk defined the neural lace as a "digital layer above the cortex" that would not necessarily imply extensive surgical insertion but ideally an implant through a vein or artery. Musk explained that the long-term goal is to achieve “symbiosis with artificial intelligence”, which he perceives as an existential tread to humanity, if it goes unchecked. As of 2017, some can interpret brain signals and allow disabled people to control their prosthetic arms and legs. Musk spoke of aiming to link that technology with implants that, instead of actuating movement, can interface at broadcast speed] with other types of external software and gadgets.

As of 2020, Neuralink is headquartered in San Francisco Mission, sharing the former pioneer truck factory, with Open AI,, another company co-founded by Musk. Musk was the majority owner of Neuralink as of September 2018, but did not hold an executive position. Jared Birchall was listed as CEO, CFO and president of Neuralink in 2018; his role has been described as formal. An August 2020 tweet confirmed past reports that Musk is the current CEO. The trademark "Neuralink" was purchased from its previous owners in January 2017.

At a live demonstration in August 2020, Musk described one of their early devices as "a Fitbit in your skull" which could soon cure paralysis, deafness, blindness, and other disabilities.

2.2 Brain Computer Interface

Brain–computer interfaces (BCIs) measure brain activity, extract features from that activity, and convert those features into outputs that replace, restore, enhance, supplement, or improve human functions.

BCIs may replace lost functions, such as speaking or moving. They may restore the ability to control the body, such as by stimulating nerves or muscles that move the hand. BCIs have also been used to improve functions, such as training users to improve the remaining function of damaged pathways required to grasp. BCIs can also enhance function, like warning a sleepy driver to wake up. Finally, a BCI might supplement the body's natural outputs, such as through a third hand.

Different techniques are used to measure brain activity for BCIs. Most BCIs have used electrical signals that are detected using electrodes placed invasively within or on the surface of the cortex, or noninvasively on the surface of the scalp [electroencephalography (EEG)]. Some BCIs have been based on metabolic activity that is measured noninvasively, such as through functional magnetic Resonance Imagining (fMRI).

2.3 NeuroRoots

Minimally invasive electrodes of cellular scale that approach a bio-integrative level of neural recording could enable the development of scalable brain machine interfaces that stably interface with the same neural populations over long period of time. NeuroRoots, a bio-mimetic multi-channel implant sharing similar dimension (10μm wide, 1.5μm thick), mechanical flexibility and spatial distribution as axon bundles in the brain. A simple approach of delivery is reported based on the assembly and controllable immobilization of the electrode onto a 35μm microwire shuttle by using capillarity and surface-tension in aqueous solution. Once implanted into targeted regions of the brain, the microwire was retracted leaving NeuroRoots in the biological tissue with minimal surgical footprint and perturbation of existing neural architectures within the tissue. NeuroRoots was implanted using a platform compatible with commercially available electrophysiology rigs and with measurements of interests in behavioral experiments in adult rats freely moving into maze. We demonstrated that NeuroRoots electrodes reliably detected action potentials for at least 7 weeks and the signal amplitude and shape remained relatively constant during long-term implantation. This research represents a step forward in the direction of developing the next generation of seamless brain-machine.

2.4 EEG Based Brain Machine Interfaces

Brain Interfaces are cyber physical systems that aim to harvest information's from the brain to sensing processes, and decide/actuate accordingly. Nonetheless, the brain interfaces are still in their infancy, but reaching to their maturity quickly as several initiatives are released to push forward their development (e.g., NeuraLink by Elon Musk and `typing-by-brain' by Facebook). This has motivated us to revisit the design of EEG-based non-invasive brain interfaces. Specifically, current methodologies entail a highly skilled neuro-functional approach and evidence-based a priori knowledge about specific signal features and their interpretation from a neuro-physiological point of view. Hereafter, we propose to demystify such approaches, as we propose to leverage new time-varying complex network models that equip us with a fractal dynamical characterization of the underlying processes. Subsequently, the parameters of the proposed complex network models can be explained from a system's perspective, and, consecutively, used for classification using machine learning algorithms and/or actuation laws determined using control system's theory. Besides, the proposed system identification methods and techniques have computational complexities comparable with those currently used in EEG-based brain interfaces, which enable comparable online performances. Furthermore, we foresee that the proposed models and approaches are also valid using other invasive and non-invasive technologies. Finally, we illustrate and experimentally evaluate this approach on the real EEG datasets to access.

2.5 Neuromorphic Chips

The ability of the human brain to process massive amounts of information while consuming minimal energy has long fascinated scientists. When there is a need, the brain dials up computation, but then it rapidly reverts to a baseline state. Within the realm of silicon-based computing, such efficiencies have never been possible. Processing large volumes of data requires massive amounts of electrical energy. Moreover, when artificial intelligence (AI) and its cousin's deep learning and machine learning enter the picture, the problem grows exponentially worse.

Emerging neuromorphic chip designs may change all of this. The concept of a brain-like computing architecture, conceived in the late 1980s by California Institute of Technology professor Carver Mead, is suddenly taking shape. Neuromorphic frameworks incorporate radically different chip designs and algorithms to mimic the way the human brain works—while consuming only a fraction of the energy of today's microprocessors. The computing model takes direct aim at the inefficiencies of existing computing frameworks—namely the von Neumann bottleneck-which forces a processor to remain idle while it waits for data to move to and from memory and other components. This causes slow-downs and limits more advanced uses.

Neuromorphic chips introduce a level of parallelism that doesn't exist in today's hardware, including GPUs and most AI accelerators," says Chris Eliasmith, a professor in the departments of Systems Design Engineering, and Philosophy, of the University of Waterloo in Ontario, Canada. Although today's deep learning systems rely on software to run basic neuromorphic systems using conventional field-programmable gate arrays (FPGA), central processing units (CPUs), and graphics processing units (GPUs), chips specifically designed to accomplish these tasks could revolutionize computing. Neuromorphic chips are packed with artificial neurons and artificial synapses that mimic the activity spikes that occur within the human brain—and they handle all this processing on the chip. This results in smarter, far more energy-efficient computing systems. The impact of commercial neuromorphic computing could be enormous. The technology has repercussions across a wide swath of fields, including image and speech recognition, robotics and autonomous vehicles, sensors running in the Internet of Things (IoT), medical devices, and even artificial body parts.

3. SYSTEM OVERVIEW

This section includes detailed description of block diagram of BMI and its explanations.

3.1Block Diagram and Description

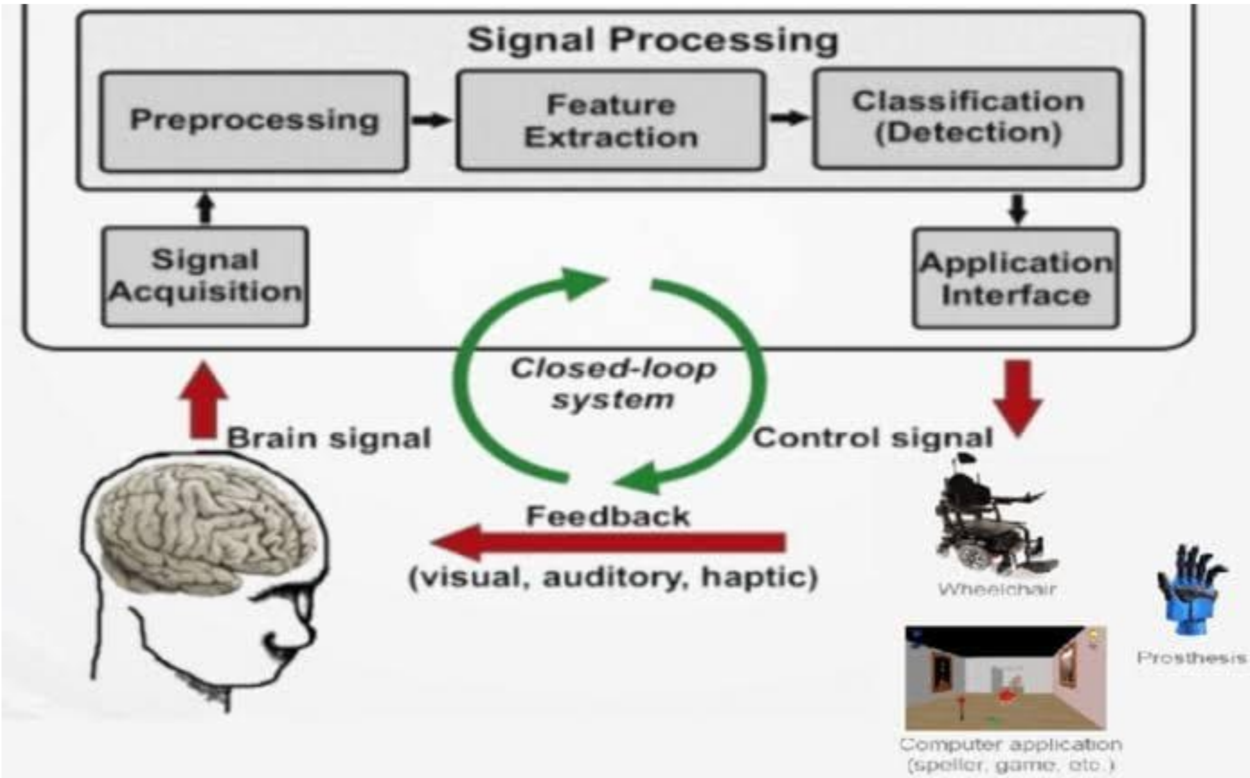

Fig.3.1: Block diagram of BMI

A BMI system consists of three components: Signal or Data Acquisition, Signal Processing (Feature Extraction, Feature Translation), and Output Device. These components are controlled by a protocol which defines the timing for operation, signal processing details, nature of device commands and the performance.

Signal Acquisition:

Signal acquisition in a BMI helps in the measurement of brain signals using a sensor modality. The sensor is basically a device implanted in the brain usually multi-electrode arrays that records the signals directly related to the movement. The signals can be amplified to levels suitable for electronic processing. Also, they can be subjected to filtering to remove electrical noise or other undesirable signals. After amplification and filtering process, the signals can be digitized and transmitted to a computer.

Feature Extraction:

Feature extraction in Brain Machine Interface (BMI) is the process of analyzing the digital signals to distinguish signal characteristics and represent them in a compact form suitable for translation into output commands. These features been extracted should have good correlations with the users intent.

Feature Translation:

Resulting signal features are passed to the feature translation algorithm, which converts the features into the commands for the output device (i.e., commands that accomplish the users need).

Output Device:

The commands from the feature translation algorithm operate the external device of the Brain Machine Interface (BMI), providing functions such as cursor control, letter selection, robotic arm operation etc. The device operation then provides feedback to the user finally, thus completing the closed loop of Brain Machine Interface (BMI).

3.2 THREADS

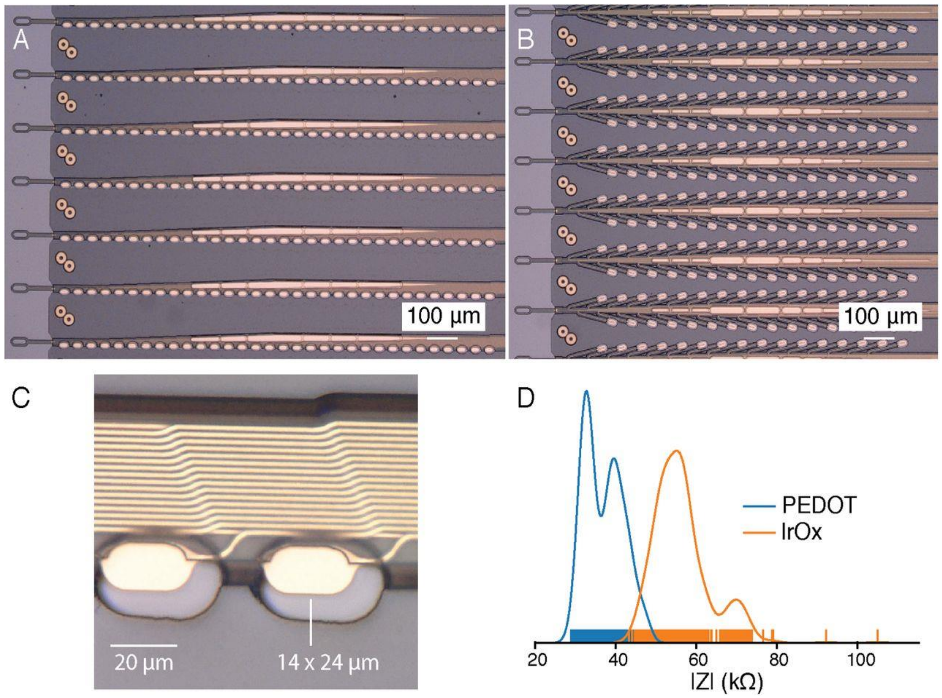

Fig.3.2:. Novel polymer probes. A. "Linear Edge" probes, with 32 electrode contacts spaced by 50 µm. B. "Tree" probes with 32 electrode contacts spaced by 75 µm. C. Increased magnification of individual electrodes for the thread design in panel A, emphasizing their small geometric surface area. D. Distribution of electrode impedances (measured at 1 kHz) for two surface treatments: PEDOT (n = 257) and IrOx (n = 588)

A custom process to fabricate minimally displacive neural probes that employ a variety of biocompatible thin film materials. The main substrate and dielectric used in these probes is polyimide, which encapsulates a gold thin film trace. Each thin film array is composed of a "thread" area that features electrode contacts and traces and a "sensor" area where the thin film interfaces with custom chips that enable signal amplification and acquisition. A wafer-level microfabrication process enables high-throughput manufacturing of these devices. Ten thin film devices are patterned on a wafer, each with 3,072 electrode contacts.

Each array has 48 or 96 threads, each of those containing 32 independent electrodes. Integrated chips are bonded to the contacts on the sensor area of the thin film using a flip-chip bonding process. One goal of this approach is to maintain a small thread cross-sectional area to minimize tissue displacement in the brain. To achieve this, while keeping channel count high, stepper lithography and other microfabrication techniques are used to form the metal film at sub-micron resolution.

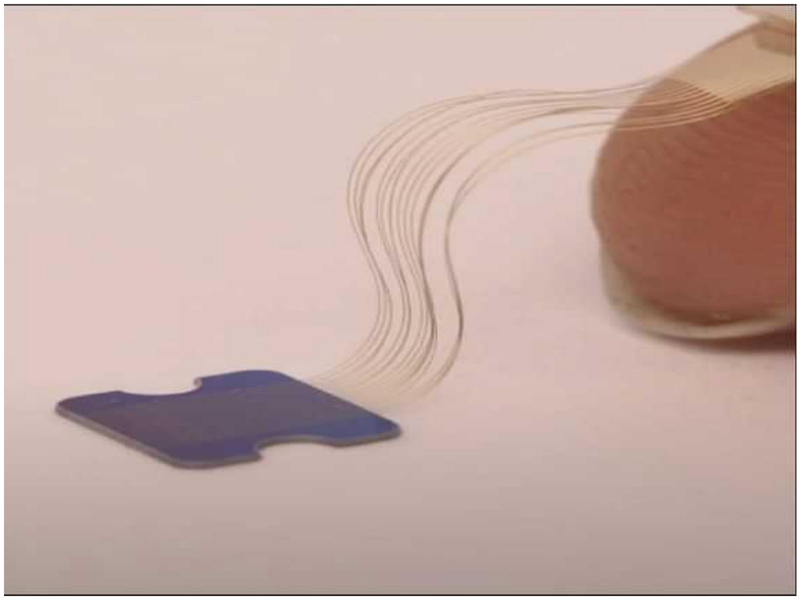

Fig.3.3: Threads compared to a finger

Designed and manufactured over 20 different thread and electrode types into the arrays. Probes are designed either with the reference electrodes on separate threads or on the same threads as the recording electrodes (referred to as “on-probe references”). We have fabricated threads ranging from 5 to 50 μm in width that incorporate recording sites of several geometries. Thread thickness is nominally 4 to 6 μm, which includes up to three layers of insulation and two layers of conductor. Typical thread length is approximately 20 mm. To manage these long, thin threads prior to insertion, parylene-c is deposited onto the threads to form a film on which the threads remain attached until the surgical robot pulls them off. Each thread ends in a (16 × 50) μm^2 loop to accommodate needle threading.

Since the individual gold electrode sites have small geometric surface area, use surface modifications to lower the impedance for electrophysiology and increase the effective charge-carrying capacity of the interface. Two such treatments that we have used are the electrically conductive polymer poly-ethylenedioxythiophene doped with polystyrene sulfonate (PEDOT:PSS) and iridium oxide (IrOx). In bench-top testing we have achieved impedances of 36.97 ± 4.68 kΩ (n = 257 electrodes) and 56.46 ± 7.10 kΩ (n = 588) for PEDOT:PSS and IrOx, respectively. The lower impedance of PEDOT:PSS is promising, however the long-term stability and biocompatibility of PEDOT:PSS is less well established than for IrOx. These techniques and processes can be improved and further extended to other types of conductive electrode materials and coatings.

To keep the electronics package small, a novel alignment and flip-chip bonding process was developed. Multi-level gold stud bumps are placed throughout the PCB to act as alignment guides and temporary holders for the thin film. A custom shuttle is used to handle, align, and place the thin film on the PCB such that through holes in the thin film slide around the stud bumps. The thin film is secured into place by applying force to the gold stud bumps which flattens them into rivets. Next, the integrated chips are bonded directly both to contacts on the sensor area of the thin film and to pads on the PCB using standard flip-chip bonding processes. A custom silicon shuttle is used to vacuum-pick-up rows of 40 to 50 capacitors and bond a total of 192 capacitors onto the PCB. This alignment and bonding process was key to creating a package containing 3,072 channels in a $(23 \times 18.5)\ mm^2$ footprint.

3.3 ROBOTS

Thin-film polymers have previously been used for electrode probes, but their low bending stiffness complicates insertions. Neuralink has developed a robotic insertion approach for inserting flexible probes, allowing rapid and reliable insertion of large numbers of polymer probes targeted to avoid vasculature and record from dispersed brain regions. The robot's insertion head is mounted on 10 μm globally accurate, 400 mm × 400 mm × 150 mm travel three-axis stage, and holds a small, quick-swappable, "needle-pincher" assembly.

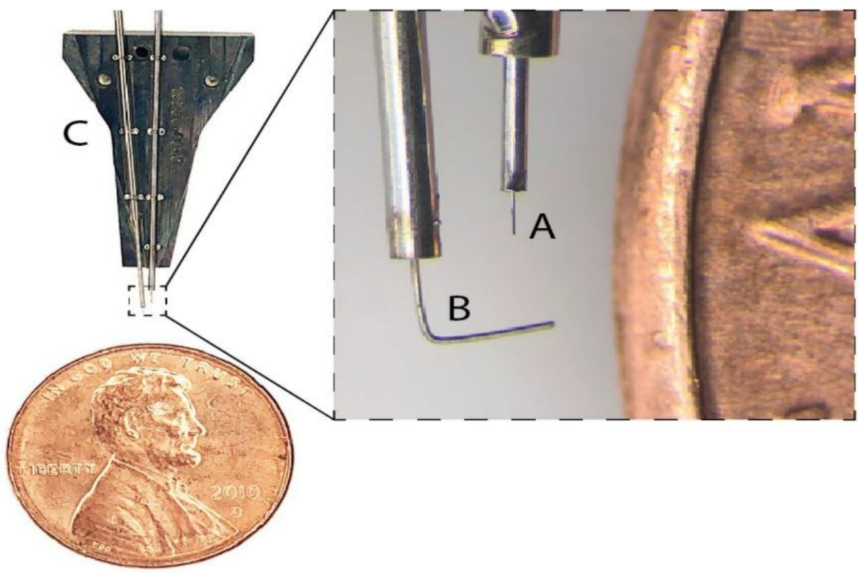

Fig.3.4: Needle pincher cartridge (NPC) compared with a penny for scale.

A. Needle. B. Pincher. C. Cartridge.

The needle is milled from 40 μm diameter tungsten-rhenium wire-stock electrochemically etched to 24 μm diameter along the inserted length. The tip of the needle is designed both to hook onto insertion loops—for transporting and inserting individual threads—and to penetrate the meninges and brain tissue. The needle is driven by a linear motor allowing variable insertion speeds and rapid retraction acceleration (up to 30,000 mm s^{-2}) to encourage separation of the probe from the needle.

The pincher is a 50 µm tungsten wire bent at the tip and driven both axially and rotationally. It serves as support for probes during transport and as a guide to ensure that threads are inserted along the needle path shows a sequence of photographs of the insertion process into an agarose brain proxy.

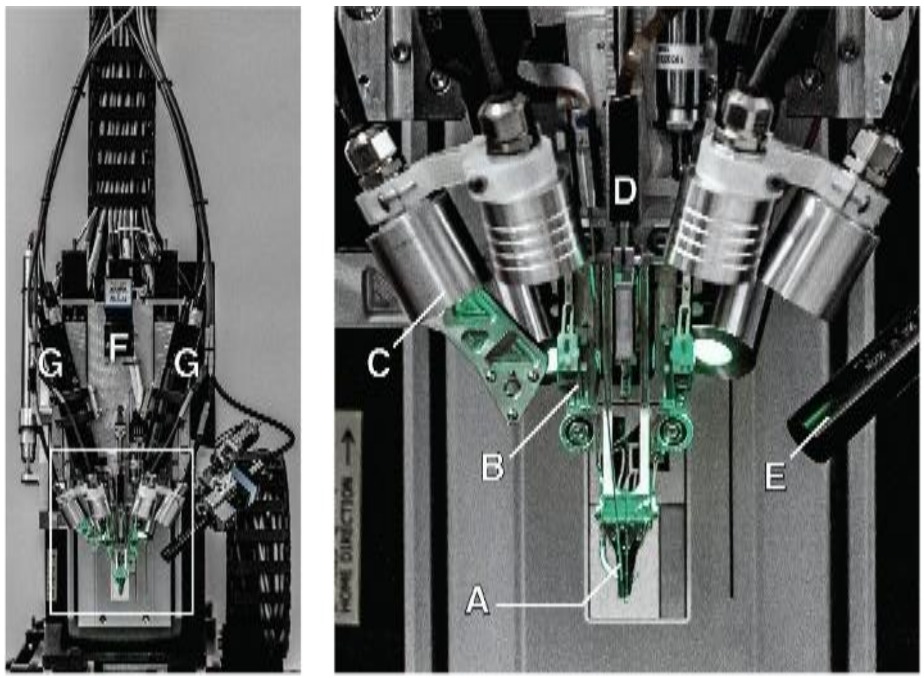

Fig.3.5: The robotic electrode inserter; . A. Loaded needle pincher cartridge. B. Low-force contact brain position sensor. C. Light modules with multiple independent wavelengths. D. Needle motor. E. One of four cameras focused on the needle during insertion. F. Camera with wide angle view of surgical field. G. Stereoscopic cameras.

The inserter head also holds an imaging stack used for guiding the needle into the thread loop, insertion targeting, live insertion viewing, and insertion verification. In addition, the inserter head contains six independent light modules, each capable of independently illuminating with 405 nm, 525 nm and 650 nm or white light). The 405 nm illumination excites fluorescence from polyimide and allows the optical stack and computer vision to reliably localize the (16 × 50)

μm^2 thread loop and execute sub-micron visual servoing to guide, illuminated by 650 nm the needle through it. Stereoscopic cameras, software based monocular extended depth of field calculations, and illumination with 525 nm light allow for precise estimation of the location of the cortical surface.

The robot registers insertion sites to a common coordinate frame with landmarks on the skull, which, when combined with depth tracking, enables precise targeting of anatomically defined brain structures. An integrated custom software suite allows pre-selection of all insertion sites, enabling planning of insertion paths optimized to minimize tangling and strain on the threads. The planning feature highlights the ability to avoid vasculature during insertions, one of the key advantages of inserting electrodes individually. This is particularly important, since damage to the blood-brain barrier is thought to play a key role in the brain's inflammatory response to foreign objects.

The robot features an auto-insertion mode, which can insert up to 6 threads (192 electrodes) per minute. While the entire insertion procedure can be automated, the surgeon retains full control, and if desired, can make manual micro-adjustments to the thread position before each insertion into the cortex. The neurosurgical robot is compatible with sterile shrouding, and has features to facilitate successful and rapid insertions such as automatic sterile ultrasonic cleaning of the needle. The needle pincher cartridge is the portion of the inserter head that makes direct contact with brain tissue and is a consumable that can be replaced mid-surgery in under a minute.

With this system, we have demonstrated an average of 87.1 ± 12.6 % (mean ± s.d.) insertion success rate over 19 surgeries. In this study, precise manual adjustments were made to avoid microvasculature on the cortical surface, slowing total insertion time from the fastest possible. Even with these adjustments, the total insertion time for this study averaged ~45 min, for an approximate insertion rate of 29.6 electrodes per minute. Insertions were made in a (4 × 7) mm^2 bilateral craniotomy with >300 µm spacing between threads to maximize cortical coverage. This demonstrates that robotic insertion of thin polymer electrodes is an efficient and scalable approach for recording from large numbers of neurons in anatomically defined brain regions.

3.4 ELECTRONICS

Chronic recording from thousands of electrode sites presents significant electronics and packaging challenges. The density of recording channels necessitates placing the signal amplification and digitization stack within the array assembly, otherwise the cable and connector requirements would be prohibitive. This recording stack must amplify small neural signals (<10 μV_{RMS}) while rejecting out-of-band noise, sample and digitize the amplified signals, and stream out the results for real-time processing—all using minimal power and size.The electronics are built around our custom Neuralink application specific integrated circuit (ASIC), which consists of 256 individually programmable amplifiers (“analog pixels”), on-chip analog-to-digital converters (ADCs), and peripheral control circuitry for serializing the digitized outputs. The analog pixel is highly configurable: the gains and filter properties can be calibrated to account for variability in signal-quality due to process variations and the electrophysiological environment. The on-chip ADC samples at 19.3 kHz with 10 bit resolution. Each analog pixel consumes 5.2 µW and the whole ASIC consumes ~6 mW, including the clock drivers.

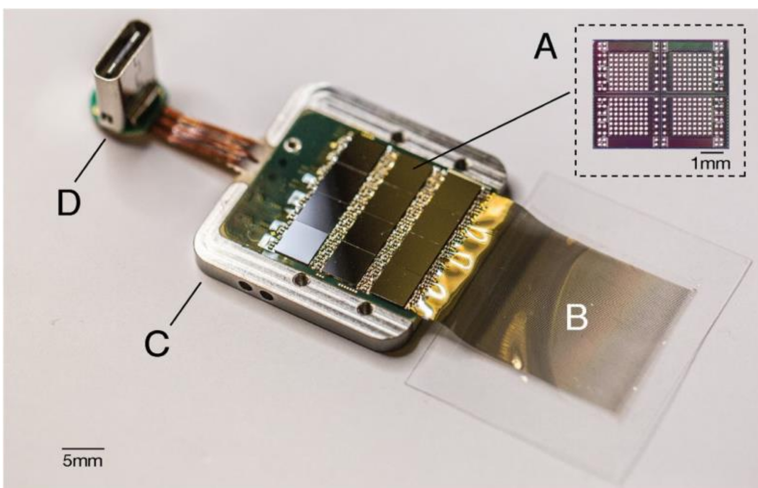

Fig.3.6:Sensor device: A- ASIC, B-Threads, C- Titanium enclosure (without lid), D- USB-C port for power and data transmission

The Neuralink ASIC forms the core of a modular recording platform that allows for easy replacement of constitutive parts for research and development purpose. In the systems discussed here, a number of ASICs are integrated into a standard printed circuit board (PCB) using flip-chip integration. Each system consists of a field-programmable gate array (FPGA); real-time temperature, accelerometer, and magnetometer sensors; and a single USB-C connector for full-bandwidth data transfer. The systems are packaged in titanium cases which are coated with parylene-c, which serves as a moisture barrier to prevent fluid ingress and prolong functional lifetime.

An ethernet-connected base station converts the data streams from these systems into multicast 10G ethernet UDP packets allowing downstream users to process the data in a variety of ways, e.g. visualizing the data in real-time or writing it to disk. Each base station can connect to up to three implants simultaneously. These devices are further supported by a software ecosystem that allows for plug and play usability with zero configuration: neural data begins streaming automatically when a cable is connected.

3.5 ELECTROPHYSIOLOGY

All animal procedures were performed in accordance with the National Research Council's Guide for the Care and Use of Laboratory Animals and were approved by the Neuralink Institutional Animal Care and Use Committee. Electrophysiological recordings were made as the animals freely explored an arena equipped with a commutated cable that permitted unrestricted movement. System A can record 1,344 out of 1,536 channels simultaneously, the exact channel configuration can be arbitrarily specified at the time of recording; system B can record from all 3,072 channels simultaneously. Digitized broadband signals were processed in real-time to identify action potentials (spikes) using detection algorithm.

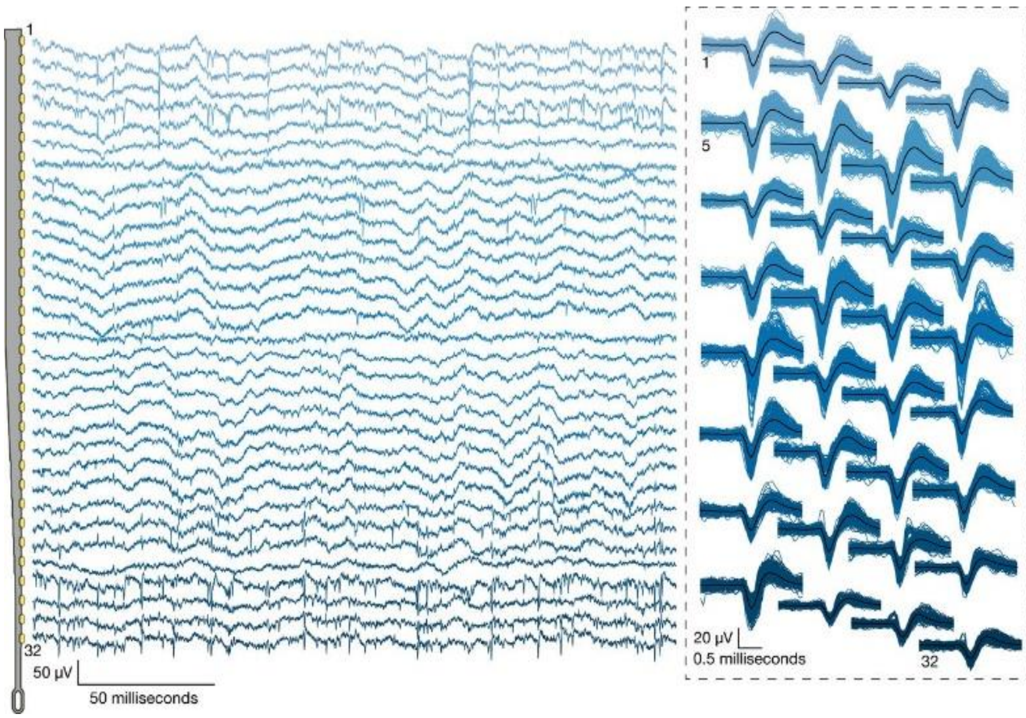

Fig.3.7: .Left: Broadband neural signals (unfiltered) simultaneously acquired from a single thread (32 channels) implanted in rat cerebral cortex. Each channel (row) corresponds to an electrode site on the thread (schematic at left; sites spaced by 50 µm). Spikes and local field potentials are readily apparent. Right: Putative waveforms (unsorted); numbers indicate channel location on thread. Mean waveform is shown in black.

Spike detection requirements for real-time BMI are different from most conventional neurophysiology. While most electrophysiologists spike-sort data offline and spend significant effort to reject false-positive spike events, BMI events must be detected in real time and spike detection parameters must maximize decoding efficacy. Using custom online spike-detection software, we found that a permissive filter that allows an estimated false positive rate of ~0.2 Hz performs better than setting stringent thresholds that may reject real spikes (data not shown).

Given these considerations, set a threshold of >0.35 Hz to quantify the number of electrodes that recorded spiking units. Since we typically do not spike sort our data, we do not report multiple units per channel. BMI decoders commonly operate without spike sorting with minimal loss of performance. Moreover, recent results show that spike sorting is not necessary to accurately estimate neural population dynamics.

In this experiment, 40 of 44 attempted insertions were successful (90 %) for a total of 1280 implanted electrodes, of which 1,020 were recorded simultaneously. The broadband signals recorded from a representative thread show both local field and spiking. A sample output of the spike detection pipeline is shown in raster form. In this example, two overlapping recording configurations were used to record from all 1,280 implanted channels. On this array, our spiking yield was 43.4 % of channels, with many spikes appearing on multiple neighboring channels, as has been observed in other high-density probes. On other System A arrays observed 45.60 ± 0.03 % (mean ± s.e.m.) across 19 surgeries with a maximum spiking yield of 70 %.

4. RESULT AND ANALYSIS

Described a BMI with high-channel count and single-spike resolution. It is based on flexible polymer probes, a robotic insertion system, and custom low-power electronics. This system serves two main purposes: it is a research platform for use in rodents and serves as a prototype for future human clinical implants. The ability to quickly iterate designs and testing in rodents allows for the rapid refinement of devices, manufacturing processes, and software. Because it is a research platform, the system uses a wired connection to maximize the bandwidth for raw data streaming. This is important for performance assessments and crucial for the development of signal processing and decoding algorithms. In contrast, the clinical devices that will derive from this platform will be fully implantable—which requires hermetic packaging—and have on-board signal compression, reduced power consumption, wireless power transmission, and data telemetry through the skin without percutaneous leads.

Modulating neural activity will be an important part of next-generation clinical brain-machine Interfaces. For example provide a sense of touch or proprioception to neuroprosthetic movement control. Therefore, we designed the Neuralink ASIC to be capable of electrical stimulation on every channel, although we have not demonstrated these capabilities here.

This BMI system has several advantages over previous approaches. The size and composition of the thin-film probes are a better match for the material properties of brain tissue than commonly used silicon probes, and therefore may exhibit enhanced biocompatibility. Also, the ability to choose where our probes are inserted, including into sub-cortical structures, allows us to create custom array geometries for targeting specific brain regions while avoiding vasculature. This feature is significant for creating a high-performance BMI, as the distribution of electrodes can be customized depeon the task requirements. Lastly, the miniturization and design of the Neuralink ASIC affords great flexibility in system design and supports very high channel counts within practical size and power constraints.

Approach to brain-machine interfaces is highly extensible and scalable. Here report simultaneous broadband recording from over 3,000 inserted electrodes in a freely moving rat. In a larger brain, multiple devices with this architecture could be readily implanted, and we could therefore interface with many more neurons without extensive re-engineering. Further development of surgical robotics could allow us to accomplish this without dramatically increasing surgery time.

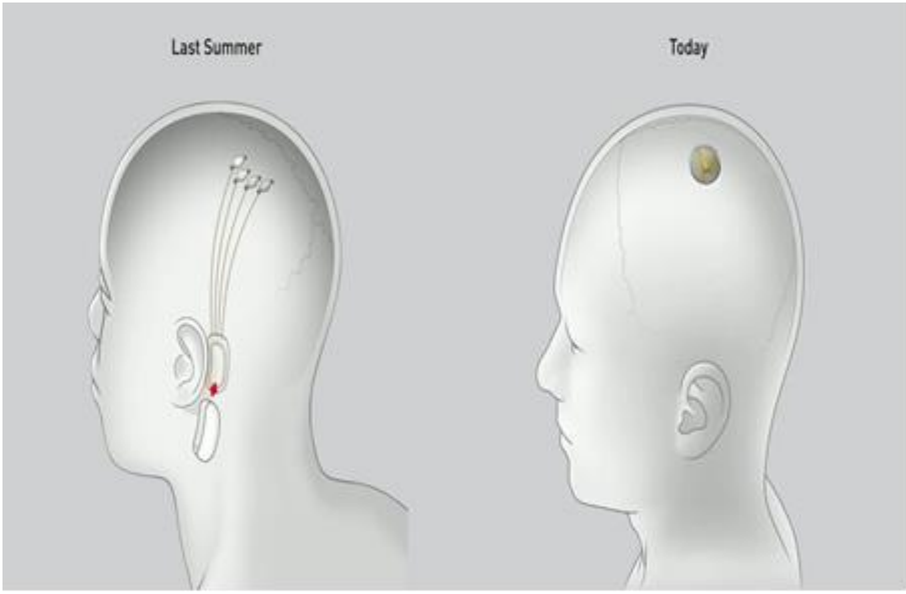

Fig.4.1: Architecture of Neuralink (The Neuralink has been simplified from a device behind the ear to one on top of the skull)

While significant technological challenges must be addressed before a high-bandwidth device is suitable for clinical application, with such a device, it is plausible to imagine that a patient with spinal cord injury could dexterously control a digital mouse and keyboard. When combined with rapidly improving spinal stimulation techniques. in the future this approach could conceivably restore motor function. High-bandwidth neural interfaces should enable a variety of novel therapeutic possibilities.

5. APPLICATIONS

Neuralink have different applications in various fields. They are given below:

- Visual prosthesis for people who have retinal injury or blindness through eye injury.
- Cure neurological conditions like Alzheimer's, dementia and spinal cord injuries.
- Can control any electronic devices and robots wirelessly using our thoughts.
- Treat memory loss, hearing loss, depression and insomnia.
- Ability to communicate more easily via text or speech synthesis, to follow their curiosity on the web, or to express their creativity through photography, art, or writing apps.
- Help people with paralysis to regain independence through the control of computers and mobile devices

6. ADVANTAGES AND DISADVANTAGES

It is important to know the advantages and disadvantages of a technology before implementing.

The advantages and disadvantages of Neuralink are studied and reported as follows:

ADVANTAGES

- Cure paralysis.
- Robots with your thoughts.
- Threat mental illness.
- Extend the range of hearing.
- Gives visual prosthesis for people who have retinal injury or blindness.

DISADVANTAGES

With every new innovation there has some down streams

- Need regular upgrades
- Brain hacking

7. FUTURE SCOPES

- For Telepathy

One might actually send the true thoughts and communicate far better.

- Unlocking Hidden Creativity

Suppose you close your eyes and conjure up an incredible like dolly-esque scene but you know if I wanted to actually show someone that it would take years of honing a craft to be able to paint it. With enough electrodes in the right places you could begin to sort of tap into those raw concepts or thought vectors and be able to decode that and show people primitive versions of music or even 3D model for engineering.

- Nostalgia On Demand

Memories fade. They get replaced, edited through narratives. As years pile up, the original version is no longer there. But like music, one can go revisit the memory and alter the mood on demand.

8. CONCLUSION

The rise of Artificial Intelligence (AI), and unnerving prophecies of a world taken over by machines, has been a pet peeve of Musk, and Neuralink is a system which could, sometime in the far future, help in that symbiosis. In its primary stages, it can assist paraplegics and other patients of Alzheimer's, dementia, and neurologically disabled people to control artificial limbs and other connected devices with thoughts. As the technology evolves further, Musk expects perfect human-computer symbiosis, or linking our conscience to an intelligent. This is technology is very young at this stage and can have a bright future depending upon how well it is being received by the consumers. The vision of this technology can be fulfilled if it works properly without glitching otherwise it can become a disaster which wouldn't create a great image. For it to work, the technology must become reliable and shouldn't have a price which could be paid by some affluent persons. The Link is a starting point for a new kind of brain interface. As our technology develops, we will be able to increase the channels of communication with the brain, accessing more brain areas and new kinds of neural information. This technology has the potential to treat a wide range of neurological disorders, to restore sensory and movement function, and eventually to expand how we interact with each other, with the world, and with ourselves. Neuralink can be one of the biggest inventions/researches of the century if everything goes right as their mission as well as vision can be felt by most of us. The need of time will only decide.

REFERENCES

[1] Abhinav Kulshreshth, Abhineet Anand, Anupam Lakanpal “*Neuralink- An Elon Musk Start-up*”. IEEE, July 2019.

[2] Wei Wang et al. “*An Electrocardiographic Brain Interface in an Individual with Tetraplegia*”. IEEE, Mar 2013.

[3] Tyson Aflalo et al. “*Decoding motor imagery from the posterior parietal cortex of a tetraplegic human*”. In: Science **348** (2015), pp. 906–910. issn: 0036-8075.

[4] Leigh R. Hochberg et al. “*Reach and grasp by people with tetraplegia using a neutrally controlled robotic arm*”. In: Nature **485** (2012), p. 372. issn: 1476-4687.

[5] Jennifer L Collinger et al. “*High-performance neuroprosthetic control by an individual with tetraplegia*”. In: The Lancet **381** (2013), pp. 557–564. issn: 0140-6736.

[6] Gopala K. Anumanchipalli, Josh Chartier, and Edward F. Chang. “*Speech synthesis from neural decoding of spoken sentences*”. In: Nature **568** (2019), pp. 493–498. issn: 0028-0836.

[7] György Buzsáki, Costas A. Anastassiou, and ChristofKoch. “*The origin of extracellular fields and currents — EEG, ECoG, LFP and spikes*”. In: Nature Reviews Neuroscience **13** (2012), p. 407. issn: 1471-0048.

[8] Neuralink, Elon Musk (2019). “*An integrated brain-machine interface platform*”. Elon Musk and Neuralink.

[9] [1] Miguel A. L. Nicolelis et al. “*Chronic, multisite, multielectrode recordings in macaque monkeys*”. In: Proceedings of the National Academy of Sciences 100.19 (2003), pp. 11041–11046. issn: 0027-8424.

[10] S.F. Cogan, T. D. Plante, and J. Ehrlich. “*Sputtered Iridium Oxide Films (SIROFs) for Low-Impedance Neural Stimulation and Recording Electrodes*”. In: The 26th Annual International Conference of the IEEE Engineering in Medicine and Biology Society 2 (2004), pp. 4153–4156.

[11] Leigh R. Hochberg et al. "*Neuronal ensemble control of prosthetic devices by a human with tetraplegia*". In: Nature 442 (2006), p. 164. issn: 1476-4687.

[12] K. D. Wise et al. "*Microelectrodes, Microelectronics, and Implantable Neural Microsystems*". In: Proceedings of the IEEE 96.7 (2008), pp.1184–1202. issn: 0018-9219.

[13] Joseph E O'Doherty et al. "*Active tactile exploration using a brain-machine-brain interface*". In: Nature 479 (2011). issn: 1476-4687.

[14] Leigh R. Hochberg et al. "*Reach and grasp by people with tetraplegia using a neurally controlled robotic arm*". In: Nature 485 (2012), p. 372. issn: 1476-4687.

[15] György Buzsáki, Costas A. Anastassiou, and Christof Koch. "*The origin of extracellular fields and currents — EEG, ECoG, LFP and spikes*". In: Nature Reviews Neuroscience 13 (2012), p. 407. issn: 1471-0048.

[16] Jennifer L Collinger et al. "*High-performance neuroprosthetic control by an individual with tetraplegia*". In: The Lancet 381 (2013), pp. 557–564. issn: 0140-6736.

[17] Wei Wang et al. "*An Electrocorticographic Brain Interface in an Individual with Tetraplegia*". In: PLoS ONE 8 (2013), e55344.

[18] Tyson Aflalo et al. "*Decoding motor imagery from the posterior parietal cortex of a tetraplegic human*". In: Science 348 (2015), pp. 906–910. issn: 0036-8075.

[19] Nicholas M. Dotson et al. "*A Large-Scale Semi-Chronic Microdrive Recording System for Non-Human Primates*". In: Neuron 96 (2017), 769–782.e2. issn: 0896-6273.

[20] James J. Jun et al. "*Fully integrated silicon probes for high-density recording of neural activity*". In: Nature 551 (2017), p. 232. issn: 1476-4687.

[21] Marc D. Ferro et al. "*NeuroRoots, a bio-inspired, seamless Brain Machine Interface device for long-term recording*." In: bioRxiv (2018), p. 460949.

[22] Fabien B. Wagner et al. "*Targeted neurotechnology restores walking in humans with spinal cord injury*". In: Nature 563 (2018), pp. 65–71. issn: 0028-0836.

[23] Tiothy L Hanson et al. "*The 'sewing machine' for minimally invasive neural recording*". In: bioRxiv (2019).

[24] Regalado, Antonio (Aug 30, 2020). *"Elon Musk's Neuralink is neuroscience-theater*". MIT Technology Review.

[25] Neuralink. (2019, July 16). "*Neuralink Launch Event"*. United States: Neuralink.

[26] Tal Dadia & Dov Greenbaum; "*Neuralink: The Ethical 'Rithmatic of Reading and Writing to the Brain*" Vol 10, issue 4(2019).

[27] Neuralink progress Update, Summer 2020, Neuralink, 28 August 2020.

[28] Conger, Kate. "*Elon Musk unveils brain chip implant: 'It's like a Fitbit in your skull"*. BBC News Aug 2020.

[29] Leigh R. Hochberg et al. *"Neuronal ensemble control of prosthetic devices by a human with tetraplegia"*. IN: Nature 442 (2006), p. 164. Issue: 1476-4687.

[30] Rucci, M., Edelman, G. M. and Wray, J. (1999). "*Adaptation of orienting behavior*": from the barn owl to a robotic system IEEE Transactions on Robotics and Automation.