

Summary of “An Integrated Brain-Machine Interface Platform With Thousands of Channels” by Elon Musk and Neuralink

Many physical ailments have long been eluding modern medical treatment, but the field of biomedical engineering has fortunately shown great promise in the restoration of bodily functions and autonomy. However, despite these advancements, current approaches in brain-machine interfaces (BMIs) face significant challenges, particularly in achieving high-fidelity recording from large neuronal populations. Indeed, noninvasive methods can cover millions of neurons, but suffer from distortion and low signal specificity. Conversely, invasive techniques provide precise readings, though only from thousands of neurons due to the use of microelectrodes. Moreover, the rigidity of these electrodes has been known to trigger immune responses (e.g., glial scarring), which can reduce their lifespan and effectiveness.

Previous research has explored various materials and designs to address these obstacles. Specifically, thin and flexible polymer probes are deemed an appealing alternative to rigid metal arrays due to their greater biocompatibility. However, one major constraint of these probes lies in their lack of stiffness, which prevents direct brain insertion. As a result, additional methods like injections or stiffeners are necessary, though these can be slow and imprecise.

This study reports Neuralink’s advancements in the development of a flexible and scalable BMI system to mitigate these limitations. Their contributions comprise three main components: ultra-fine polymer probes, a neurosurgical robot, and miniaturized custom high-density electronics.

The polymer probes are made from polyimide, which encapsulates a thin gold film and are organized into 48 to 96 threads per array. Each thread is 20 millimetres long and contains 32 independent electrodes, while a sensor area connected to custom chips allows signal amplification and acquisition. This design, combined with a novel alignment and flip-chip bonding process, achieves a high channel count of 3072 electrodes per array and minimizes tissue displacement.

The neurosurgical robot addresses the challenges of efficiently and safely inserting a large number of these probes. It can autonomously implant up to six threads per minute using a tungsten-rhenium needle, and has achieved an average success of 87.1% over 19 surgeries. The robot’s ability to avoid blood vessels and target specific brain regions minimizes damage and significantly improves recording fidelity in comparison to previous insertion techniques.

The electronics, built around Neuralink’s custom application-specific integrated circuit (ASIC), support real-time streaming of neural signals from thousands of channels with minimal power consumption. The ASIC features 256 individually programmable amplifiers, on-chip analog-to-digital converters, and peripheral control circuitry.

To evaluate the performance of the developed system, experimental trials were conducted on male Long-Evan rats, with a 1536-channel recording system successfully inserted in 40 out of 44 attempts for a total of 1280 electrodes, 1020 of which were recording simultaneously. The system captured both local field potentials and individual neuronal spikes in real time, with 43.4% to 45.6% of electrodes detecting neural activity and a maximum yield of 70%. This demonstrates the system’s efficiency in implant insertion, as well as its capability for high-density and high-fidelity recording.

The current system serves as a research platform for rodent studies while also paving the way for future human clinical implants. While the present setup uses wired connections for performance assessment and algorithm development, future clinical devices will be fully implantable, featuring hermetic packaging, on-board signal compression, reduced power consumption, wireless power transmission, data telemetry, and the potential for neural activity modulation. Neuralink’s extensible and scalable high-bandwidth BMI could permit the insertion of multiple devices in a larger brain in the future. This could, in turn, allow a patient with spinal cord injury to effortlessly yet precisely control a digital mouse. It may even restore motor functions when combined with spinal simulation techniques. These possibilities effectively highlight the potential range of applications of the device.