PreScouter

Can we control machines with only our minds?

Research Support Service

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Inquiry Question

Can we control machines with only our minds?

What if we didn't have to physically intervene between our thoughts and a machine's action? Imagine how it would feel to move a formerly paralyzed limb, or the convenience of simply thinking where you want your car to take you, and away it goes. Thinking of grocery items you need, and a list is immediately sent to Alexa and ordered. We are close now, with pre-programmed intermediate steps decreasing the time between thought and action.

The vision, then, will be to eliminate that lag. With the current tech boom, it's not hard to imagine thought-to-action coming to fruition; but HOW and WHEN will we get there? This inquiry identifies the key technologies bringing us closer to a brain-computer interface (BCI) and highlights a few examples for each.

Executive Summary

The principal objectives of brain-computer interfaces (BCIs) are to:

➔ **Detect** threats to the human brain

➔ **Emulate** functional brain networks to efficiently reproduce natural information synthesis

➔ **Restore** behavioral or cognitive function lost as a result of injury

➔ **Improve** functional behaviors and accelerate learning

A major barrier to mass implementation of BCIs has been consumer apprehension to have electrodes surgically implanted. So, inventors are increasing focus on non-invasive alternatives that could see broader uptake. We highlight several such technologies in this report.

Four enabling technologies for BCIs have been identified:

1) **Non-invasive sensors:** Such technologies provide a link between the brain and computer without any invasive procedures. Examples covered include the University of Minnesota's 3D neural map and MIT's AlterEgo.

Executive Summary

2) **Flexible biocompatible fibers:** The goal of these fibers is to decrease the response time lag of the relayed messages. Innovations from Dyconex and the University of Singapore are explored.

3) **Signal mapping arrays:** This technology aims to restore motor function as a result of injury. Advances from San Diego State University and the University of Pittsburgh are highlighted.

4) **Sensor electrode substrate materials:** Such materials can be employed in enhancing the functional behavior and learning capabilities of patients. Two materials covered are Virginia Commonwealth's Flexible Electrode and the Berlin Institute of Technology's Passive Dry EEG Electrode.

Note: *This report is not meant to be comprehensive, but rather to highlight exciting examples of innovative and transformative technologies that demonstrate work toward specific features required to create brain-computer interfaces.*

Non-Invasive Sensor Technology

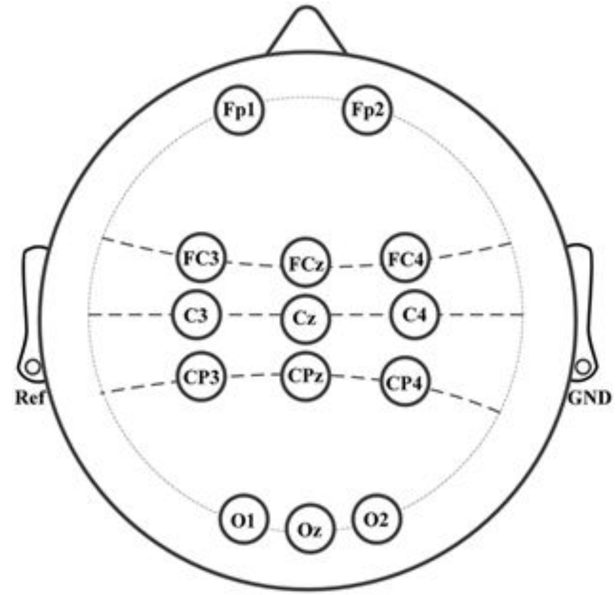
University of Minnesota - 3D Neural Map

The University of Minnesota used electroencephalography (EEG) to study neural activity. Processing the data collected from the sensors is critical in reducing the signature of the brain activity in the three spatial dimensions, as well as time and frequency.

EEG signals are filtered with:

- Component analysis (initial de-noising)
- Laplacian filtering (special resolution enhancement)
- Wavelet decomposition (motor imagery)

The regressed signature can be applied to a specific motor imagery task, leading to definition of the intention of thought patterns.



Layout of EEG electrodes with standard international 10–20 system. Zhou B, Wu X, Lv Z, Zhang L, Guo X (2016) A Fully Automated Trial Selection Method for Optimization of Motor Imagery Based Brain-Computer Interface.

http://helab.umn.edu/eegsensing.htm

MIT - AlterEgo

Artificial intelligence approach to classify neuromuscular signals and infer user intention:

MIT has created a headset called AlterEgo, a wearable device that attaches to the jaw, where electrodes pick up neuromuscular signals triggered when the user says words in their head.

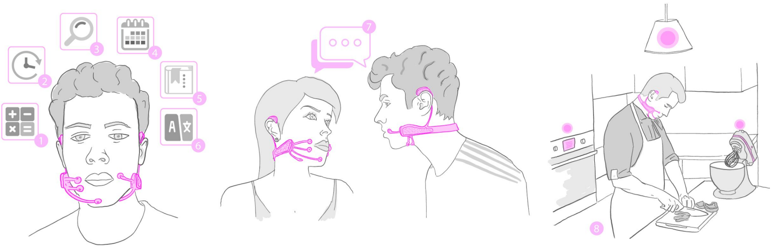
Main features of AlterEgo :

- **Silent speech:** robust recognition (92%) even when the mouth is not open
- **Portability:** ambulatory wearable system
- **Privacy:** no access to the user information unlike fMRI, DOT, EEG, etc.

Arnav Kapur, a researcher in the Fluid Interfaces group at the MI. Credit: Lorrie LeJeune, MIT

The AI model is based on:

- A **data corpus** preprocessed via the Cosine Transform (CT) and spectral power analysis
- A **Convolutional Neural Network** (CNN) to classify the data vocabulary categories



AlterEgo seeks to make computing a natural extension of the user. Credit: Arnav Kapur, Neo Mohsenvand.

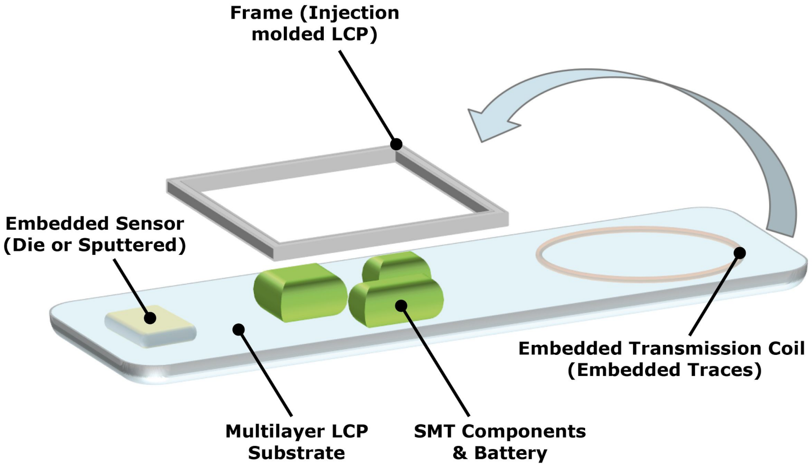
https://dl.acm.org/citation.cfm?id=3172977

Flexible Biocompatible Fibers

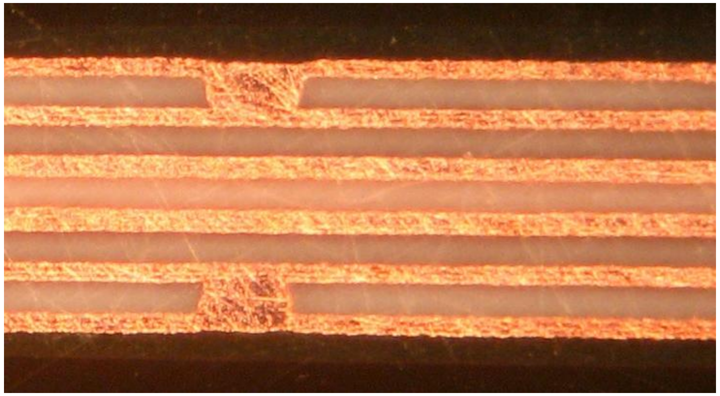
Dyconex - Multimodality Fiber

DYCONEX
an MST company

Dyconex developed multi-functional [external] fibers that analyze optical, chemical, and electrical circuits on live specimen simultaneously. Maintaining robust multi-functional capability will enhance the range of applicability of the fibers.



Miniaturized sensor package made from a LCP substrate with embedded sensors, communication coil and other components. Image courtesy of Dyconex.

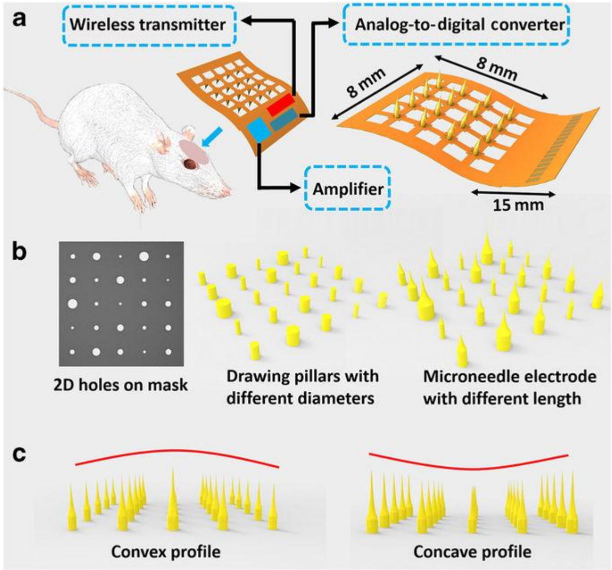


Ultra-thin 6-layer multilayer stackup with 25 μm thick LCP layers. Minimum via diameter: 30 μm. Total thickness: 182 μm. Image courtesy of Dyconex.

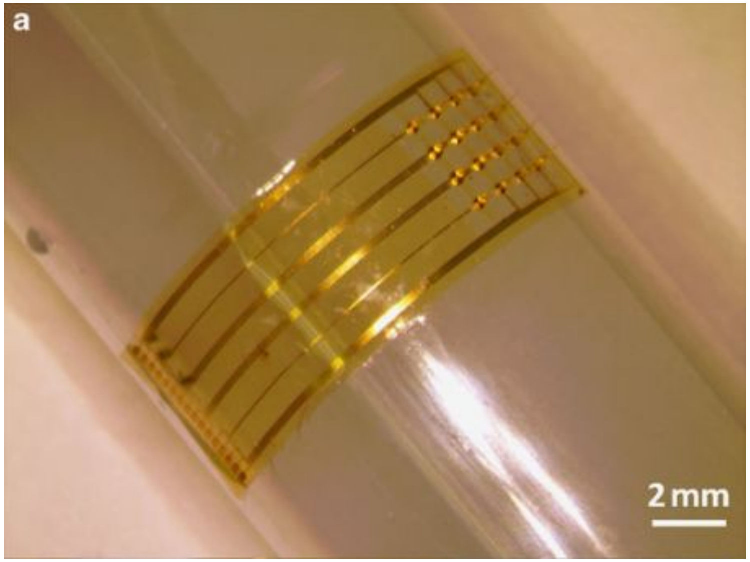
Liquid Crystal Polymer (LCP) is a flexible, biocompatible thermoplastic. It is temperature stable to 190°C, has a low density, and has very low water absorption compared to standard acrylic adhesives.

https://www.virtualmarket.ila-berlin.de/media/c375422,66234

Researchers from the **National University of Singapore** created a minimally invasive flexible 3D electrode mesh for wireless BCI prosthesis. BCIs can augment and improve existing physical capacity, and the neural interface mesh conforms comfortably to the tissue. It does not require extensive micromanufacturing, protecting cost. The study highlights improved flexibility by fabricating microneedles from drawing lithography technology.



A schematic depiction of the flexible microneedle electrode



An optical image of the flexible microneedle electrode attached to a curved surface (scale bar: 2 mm).

https://www.nature.com/articles/micronano201612

Neural Signal Mapping Arrays

San Diego State University - Highly Stable Glassy Carbon

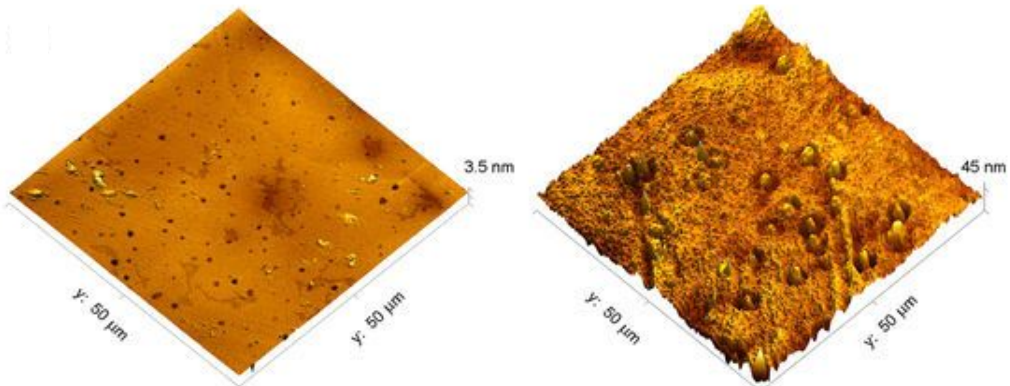
SAN DIEGO STATE UNIVERSITY

Arrays are another technology used for non-invasive neural signal mapping. Arrays are made of lithographically patterned, electrically conductive material. An example of such a material is glassy carbon, which has been studied by a research group led by San Diego State.

Historically used for in vitro (implanted) signal recording, the technology has been applied in a non-invasive approach to increase the favorability of this option.

The glassy carbon electrodes showed:

- Improved performance over platinum ones, with significantly less noise.
- This improvement leads to a clearer, more actionable analysis of the signals.



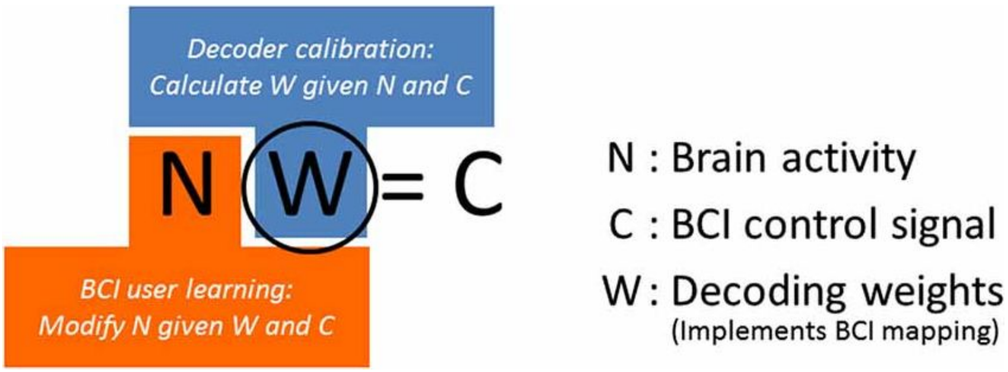
Glassy carbon (left) and platinum electrode images

https://www.nature.com/articles/srep40332

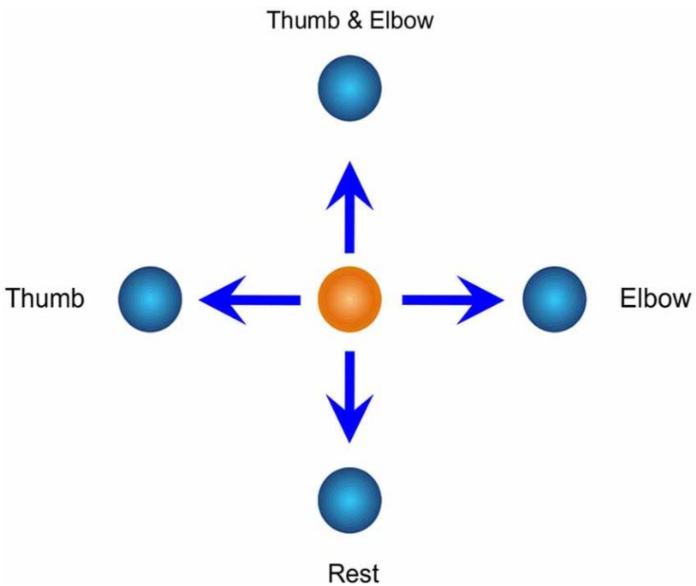
University of Pittsburgh - Microelectrode Array

A group led by the **University of Pittsburgh** developed a system using electrocorticography and intracortical microelectrode arrays to promote BCI learning. Their research focused on utilizing the technology to **restore motor function**, one of the primary objectives of BCIs.

➔ **The array maps a desired brain pattern from a properly-functioning sequence and applies it to the sequence of the inhibited motor function.**



Decoders convert neural activity to control signals to instigate movement.



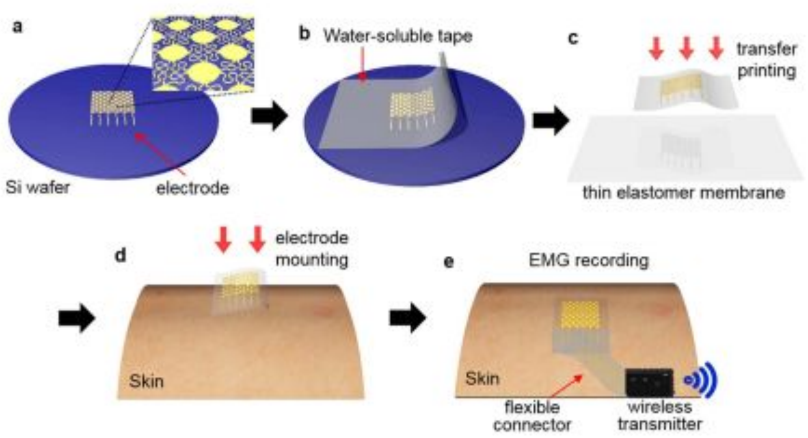
Thumb and elbow movements mapped to 2D space for cursor control.

https://www.frontiersin.org/articles/10.3389/fnint.2015.00040/full

Sensor Electrode Substrate Materials

Virginia Commonwealth University led a consortium to investigate substrate materials for *in vivo*, skin-friendly electrodes to mitigate the challenges of rigidity, non-conformity with the skin, and conductive adhesives that irritate the skin. The study investigated dysphagia rehab (to re-train swallowing behavior).

- ➔ The 1 cm^2 electrode is comprised of a soft, stretchable, ergonomic polyamide/ elastomeric substrate containing a gold nano-membrane. It uses patterns like fractal curves to achieve much better elastic mechanical properties than traditional serpentine fibers. The researchers determined that the electrodes had to withstand strains of more than 70%.



Fabrication process of a skin-like electrode and printing on the skin. (a) Fabricated gold electrode on a Si wafer. (b) Retrieved electrode from the wafer by using a water-soluble tape. (c) Transfer printing onto a thin elastomeric membrane by dissolving the tape with water. (d) Printing of the electrode on the target location of the skin by dissolving a supporting sheet of the polyvinylalcohol film. (e) Connection of a ribbon cable for wireless transmission of the recorded EMG signals.

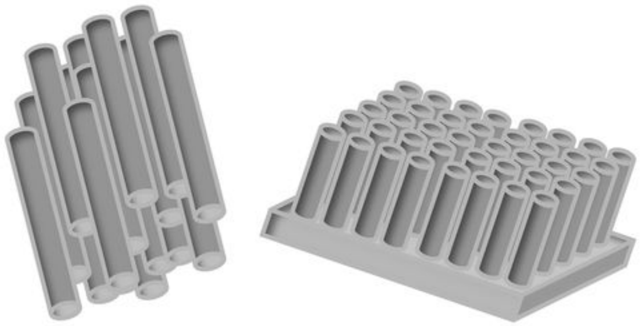
https://www.nature.com/articles/srep46697.pdf

Berlin Institute of Technology - Passive Dry EEG Electrodes

Researchers from the Berlin Institute of Technology created a low cost dry electrode for EEG. This electrode reduces the reported discomfort by distributing the pressure on the skin of the scalp more uniformly and more flexibly. The novelty consists in using flexible conductive bristles instead of pins. These bristles are made of silver-coated polymer in the reported prototype.

Main features of the Passive Dry EEG Electrodes:

- **Sensitive skin-type:** do not penetrate the skin of the head → easily accepted by users.
- **High quality recording:** increase the reliability of the contact, resulting in a high signal quality.
- **Comfort:** distributes the pressure on the skin of the scalp more uniformly and flexibly.
- **Low-cost:** cheap price compared to other types of EEG electrodes.



The silver-coated polymer bristles prototype

http://doc.ml.tu-berlin.de/bbci/publications/GroVoiFaz11.pdf

Regulations and Conclusions

Ethical Issues and Regulations

Groups like the Center for Sensorimotor Neural Engineering advocate for privacy, security, moral and legal responsibility of scientists and researchers developing BCI technology. The inherent nature of predicting recording brain signals and potential danger arising for machines immediately doing what a person thinks must be considered along advancements with motor movement and invasive technology implanting. A study from the Czech Republic examined the impact of BCI technology on human dignity, right to privacy, freedom of thought and freedom of expression. It calls for the need to incorporate risk management measures to prevent technology misuse.

It is worth noting that much of the regulatory attention concerns healthcare, and there is very little discussion on the use of BCIs for IoT and autonomous technology. A 2014 study by the US FDA outlined key consideration areas and questions related to the implementation of BCIs, which focuses on the risk tolerance of the patient depending on the specific disability. But while there is a stated need for defining regulations in the field, at the moment there is no significant regulation around BCIs due to lack of commercialized options.

http://www.csne-erc.org/research/neuroethics
https://journals.muni.cz/mujlt/article/viewFile/2655/2219
https://www.fda.gov/downloads/MedicalDevices/NewsEvents/WorkshopsConferences/UCM416692.pdf

Conclusions and Outlook

BCI technologies have seen gains in sensors, flexible fibers, neural mapping arrays, and substrate materials, making the reality of a commercially-viable option closer than ever before.

It appears healthcare will be the first niche to adopt the technology, based on both the benefit to patients and their families and the research behind healthcare BCI technology to date. Enabling technologies in that field will lead to further innovation in tangential industries, then to unrelated ones like IoT and autonomous vehicles.

Regulation will undoubtedly accompany commercialization, and the first to market will have a good opportunity to shape legislation. In addition to added convenience and motor function, BCIs will give people hope for achieving a quality life they previously may never have imagined.

Next Steps

Potential Other Inquiries that PreScouter Could Research for You

Topic	Question	Report
Sensor Technology	Do non-invasive sensors provide the same performance levels as implanted ones?	
Biocompatible Fibers	Are there manufacturing concerns in making flexible vs. rigid biocompatible fibers?	
Substrates	Are there other innovative substrate materials that could be used for BCI's?	
Regulations	What are the proposed regulations that may guide commercialization of invasive vs. non-invasive technology?	

About the Authors

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Professional Summary:

Adam is one of PreScouter's Global Scholars, as well as the Principal at ASK Consulting Solutions, a technical content writing and research consulting firm. He specializes in the alternative energy, transportation, consumer products, IT and healthcare IT industries.

Research Background:

Adam earned a B.S. in Chemical Engineering from Penn State and an M.S. in Mechanical Engineering – Energy Systems from Marquette University. His master's thesis at Marquette defined new transport correlations for steam-methane reforming in non-adiabatic, process-intensified catalytic reactors.

Scientific Interests:

Adam's scientific interests include thermodynamics and heat transfer, chemical kinetics and catalytic chemical reactors, direct-chip cooling for cloud computing, vehicle electrification, and organic chemistry for consumer use.

About the Authors

Mohamed Akrout, MS Machine Learning

University of Toronto (Canada)

Professional Summary:

Mohamed is one of PreScouter's Global Scholars. He specializes in reinforcement learning (an artificial intelligence field), neuroscience, wearable devices and healthcare IT industries.

Research Background:

Mohamed earned a B.S. in Computer Science from University of Montreal and an M.S. in Artificial Intelligence from University of Toronto. His master's topic is applied deep learning algorithms to perform skin exams with dermatologist-level accuracy.

Scientific Interests:

Mohamed's scientific interests include Machine Learning, sequential modeling, bayesian inference, high performance system (GPUs) analysis, and cloud computing.

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