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EMERGING TECHNOLOGY SNAPSHOT

BIDIRECTIONAL BRAIN-COMPUTER INTERFACES

Brain-computer interfaces (BCIs) allow the brain to interact with an environment by reading brain signals and using them to impact external objects, or by enabling external stimuli to impact the brain. Devices that can perform both operations simultaneously are called bidirectional brain-computer interfaces (bBCIs). Such devices have applications in medicine and prosthetics, but also in the entertainment, security and defence, marketing and education industries. However, despite its many promises, BCI technology poses technical, social and regulatory challenges.

ENABLING SCIENCE AND TECHNOLOGY

Invasiveness

BCIs can be invasive, non-invasive or semi-invasive. Non-invasive BCIs use sensors on the scalp to capture brain signals. These are the simplest and easiest to use as they do not require surgery. Invasive methods offer greater precision as they use sensors implanted in the brain, but this comes at the cost of requiring varying degrees of surgical procedures. In semi-invasive devices, sensors are placed on the exposed surface of the brain, but not inside it.

Components

BCIs rely on three components: a reading technology, a stimulation technology and algorithms that can decode brain signals. Electroencephalography and electrical stimulation are the most well-known and use recording and stimulation techniques respectively. Algorithms and other technologies can be used to process brain signals, but the emergence of artificial intelligence (AI) in recent years has enabled more precision in the analysis of the brain signals.

Bidirectional BCIs

Some issues are more critical in bBCIs than they are in BCIs. Real-time operation makes bandwidth and data transmission speed important factors to consider. Portability and miniaturization are also required, as the data has to be processed where the recording and stimulation take place. Decoding algorithms need to process the data faster and continually adjust to the signals received in order to stimulate the brain accordingly.

Enabling and enhanced technologies

BCIs can enhance technologies such as prosthetics and robotics, where improvements in electrodes and in decoding algorithms have accelerated the development of robotic prostheses and exoskeletons. Neurofeedback systems used in education and rehabilitation can also benefit from BCIs, by measuring brain waves and providing real-time feedback to help users self-regulate their brain functions. Finally, BCIs can make device control more intuitive and instantaneous in augmented and virtual reality gaming and entertainment.

"By adopting artificial intelligence techniques and advances in brain-sensing technology, the futuristic scenes in sci-fi movies can soon become a reality. (…) This synergistic relationship between brain and machine allows for science and emerging technology to uncover deep insights into human intelligence and capability."

Bicheng Han, founder and CEO of BrainCo

SIGNALS

Academic

Universities dominate research activity on bBCIs. Wright State and Case Western (USA) were among the first to focus on bidirectional devices, but ETH (Switzerland) and the Sant'Anna School of Advanced Studies (Italy) are now leading in the area.

Government

There are many government-funded projects in neurosciences. One is the EU's *Wearable interfaces for hAnd function recovery* project, which looks at the bidirectional flow of sensory information.

Collaboration

International collaboration in bBCI is high, with geographically-organized networks. European countries are actively co-publishing, especially Denmark and Switzerland while USA is mostly co-publishing domestically.

Defence

Military organizations have few publications on BCIs but they are strongly engaged in the area. The Defense Advanced Research Projects Agency (DARPA) is especially active, with projects like *Next-Generation Nonsurgical Neurotechnology*, which looks at bidirectional interfaces.

Corporate

Industry plays a minor role in research but many companies, mostly SMEs and start-ups, are active in the field. Companies in the area include Emotiv, InterAxon, Paradromics, Kernel and Neuralink.

"The consumer market can drive technology very quickly. (…) Researchers are (not) going to raise the billions of dollars needed to make that technology available to them. It's going to have to be driven by consumer technology. You need the much bigger market to drive that technology growth."

QDavid Boas, Professor in Radiology at Harvard Medical School and Director, Optical Imaging Core & Lab at Martinos Center

IMPACT

Social

BCIs can have positive impacts on quality of life, especially in the prosthetics and rehabilitation areas. However, neuroethicists are concerned that BCIs could also impact users' free will, which is critical considering the importance of AI in BCI.

Policy

Standards on BCIs are currently in development. Experts are asking governments to ensure that limits are set regarding privacy and data handling. Evaluation criteria and rules on human subjects' participation in studies on BCIs are required.

Economic

High costs could slow down technology adoption. Development, equipment and implantation costs are significant and may be prohibitive for many user groups, which could lead to inequity.

Environmental

The research did not identify potential environmental impacts for BCIs. Environmental science is not a major application and their fabrication does not appear to pose any particular environmental challenge.

Defence

BCIs have applications in unmanned vehicles control or for the replacement of missing limbs. They also create vulnerabilities; the integrity of the data and the brain-machine connection could be compromised by electronic warfare attacks.

"For society to be able to take full advantage of the benefits offered by neurotechnologies, we need to ensure that broader ethical, social and legal questions are addressed in real time, and that society is actively engaged in the development, and deployment, of the technologies."

Diana Bowman, associate professor in the School for the Future of Innovation in Society and the Sandra Day O'Connor College of Law

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Produced in partnership by the National Research Council of Canada and Defence Research and Development Canada.

Derived from:
Derived from: Senay, M. *Scientometric study on bidirectional brain-computer interfaces.* March, 2021

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PDF: Cat. No. NR16-366/2021E-PDF
ISBN 0978-0-660-39523-4

04·2021 • Également disponible en français