Brain-controlled computers are becoming a reality, but major hurdles remain

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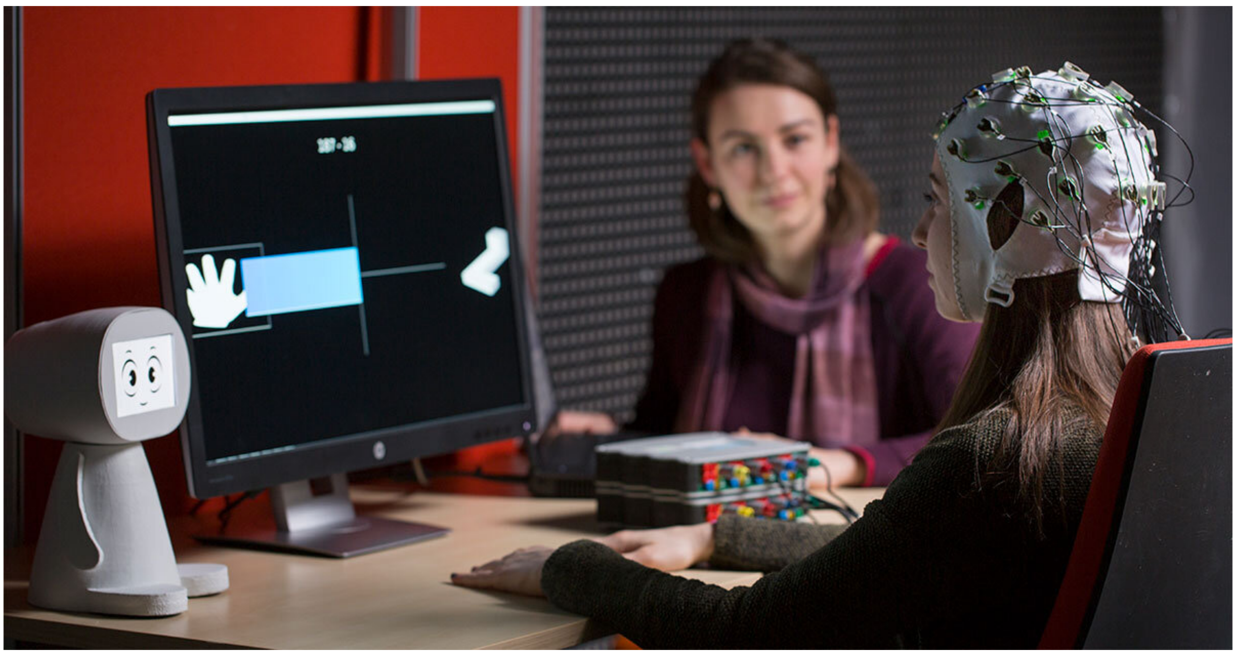

A robotic companion called PEANUT provides brain-computer interface users with social feedback, such as encouragement, while they use the system. Credit: Inria/C. Morel

Imagine controlling your computer just by thinking. It sounds far-out, but real advances are happening on these so-called brain-computer interfaces. More researchers and companies are moving into the area. Yet major challenges remain, from user training to the reality of invasive brain implant procedures.

Sensors in pig brains—that's what Elon Musk is currently working on. The entrepreneur is mainly known for his work at Tesla and SpaceX, but he's also behind Neuralink, a company promising to change brain-computer interfaces. These devices would allow humans to control computers using their brain. Neuralink is testing their new technology on pigs. During a press conference in September Musk even trotted out a pig with a brain implant that tracked stimulation of her snout.

All of this might sound like science fiction, or hype, but this research area holds promise. Brain-computer interfaces or BCIs, might in the near future help patients with brain injuries or impaired motor abilities recover or better engage with their surroundings. Someone with reduced motor abilities could control a mechanised wheelchair with their brain, or maybe even household appliances and devices like a television or thermostat without lifting a finger, increasing their independence. In the long run it might even help enhance people's cognitive capabilities. But for the moment a range of technological and human challenges remain.

Interfaces

Such challenges are what Dr. Fabien Lotte, Research Director at Inria Bordeaux-Sud-Ouest in France, is researching. "Most brain-computer interfaces work, but don't work well," he said.

There are two main types of BCIs: non-invasive and invasive. The non-invasive versions are the most common, and are simply sensors placed on the human head, like a high-tech hat full of wires. They measure brain activity and translate that data to a computer. Invasive BCIs on the other hand are sensors placed inside the skull, which is what Neuralink is exploring.

A BCI might want to make a mouse pointer go left or right based on the user's brain activity. Dr. Lotte mentions that, on average, BCIs get it right about 60% to 80% of the time, although this depends on how many mental commands are included. A system that only makes a cursor go left or right includes only two mental commands and has a higher accuracy rate of around 70% to 80%. So once every few attempts the system makes a mistake. "If a computer mouse makes that many mistakes, you wouldn't use it," Dr. Lotte said.

But for Dr. Lotte the problem might also lie not only with the technology but the people using BCIs. "Controlling a BCI is a skill you need to learn," he said. "We don't only need good technology, we also need well-trained users."

Dr. Lotte leads a research project, called BrainConquest, that designs better training for non-invasive BCI users. The researchers give the users exercises like playing a video game with their brain, where someone thinks about an action that needs to be performed on screen. But the team is also designing better feedback systems, like tactile gloves that provide vibrations on the user's hand.

Social feedback, like encouragement, is also tested. They even designed an artificial companion, called PEANUT, which looks like a cute cartoon robot, with a screen for a face. "It's very difficult to have a human teacher that is consistent," said Dr. Lotte, arguing an artificial companion offers a more uniform interpretation of brain activity and can still provide a useful feedback experience.

The research is still underway but shows notable gains in certain users. A combination of tactile and visual feedback gives on average a 5% increase in accuracy for the entire test group. PEANUT has a positive effect on people who like to work in groups. Without PEANUT their accuracy is on average 63%, which goes up between 5% and 10% depending on the user. Users who like to work alone, however, see a decrease in performance when PEANUT is present.

Data

Technology on the other hand also remains a challenge. Dr. Aaron Schurger, assistant professor at Chapman University in the US, argues that the approach to data-analysis BCIs use can be improved. Traditionally, BCIs only use the data from when users want to take an action. They, for example, collect large amounts of brain data from when a user wants to make a mouse pointer go left and use that to better realise when they need to take that action.

But Dr. Schurger argues we need to look beyond that narrow set of information, and also include data from when the brain is, say, at rest. This is a concept he previously explored in the research project ACTINIT. "We're now looking at all the data," said Dr. Schurger. "Not only the data right before a movement."

Dr. Schurger compares this to weather forecasting, where meteorologists use large amounts of weather data to make predictions about what will happen. "If you want to predict when it's going to rain, you won't do a very good job if you only look at rainy days. You will miss half the picture that way."

Yet if BCIs want to really fix the issues that are plaguing them right now, more radical action might be needed than user training or better data analysis. It will require researchers to go beyond non-invasive technologies. One key non-invasive method is called EEG or electroencephalography. Here electrodes are attached to the scalp, which measure the electrical current sent by the neurons inside the brain. "EEG measures microcurrents that reflect brain activity," said Dr. Lotte.

When an individual takes an action or thinks about it, that might fire up hundreds of thousands of neurons, thereby generating electrical current that is large enough to be measured on the scalp. Software systems then try to make sense of this data and connect it to an action or thought.

But for Dr. Schurger, EEG has effectively plateaued. "People have been working on this problem for three to four decades now, and there haven't been any major breakthroughs for a long while," he said.

Skull

The key question here is the thickness of the skull. It might protect our brain very well, but it also makes it harder to find out what's going on beneath.

"The signal from the brain is extremely weak," said Dr. Schurger. "Imagine that you position a few microphones above a packed football stadium, and you're trying to pick up on one conversation. You might realise when a goal is scored, but that single conversation is very hard to distinguish."

The solution is to go into the stadium, closer to the action. Or for BCIs, drill into the skull and attach sensors directly to the brain. This gives researchers a better signal, and invasive BCIs have been installed in humans since the late 1970s, in experimental cases where they restored partial vision in blind patients and allowed paralysed people to take control of prosthetics. But they also come with a range of medical considerations.

First, doctors need to convince patients and regulators to let them install a device inside a person's head. On top of that, there might be medical complications. A patient's body might grow immune tissue around the sensor, or even reject it. Which could lead to a worse signal for the device, or negative health effects for the patient. "There's a foreign object inside your skull," said Dr. Schurger. "The body tends to want to reject that."

For these reasons, the more futuristic applications where human and machine fuse together to enhance cognitive abilities, will probably have to wait for a while. For now, medical applications will probably dominate the field according to Dr. Schurger.

Non-invasive

But even BCI systems that don't work perfectly well still find applications. Dr. Lotte mentions that non-invasive BCIs can help rehabilitation of stroke patients, which he also explored with the Pellegrin hospital in Bordeaux. A stroke patient today already needs to exercise damaged parts of their brain by, for example, thinking about a certain action. A BCI could help the patients by giving them feedback on this brain exercise, although it's too early in the project to present results on the effectiveness.

"Here it doesn't matter that the system isn't very reliable," said Dr. Lotte. "You're not trying to control something. You're trying to re-learn how to use the area and improve the recovery."

Another use-case Dr. Lotte mentions is passive BCI. Here the technology is used to monitor brain activity. High-risk professionals like pilots could in the future wear a non-invasive BCI during a flight to monitor their fatigue and concentration. By monitoring their brain activity, other crew members can detect when they are too tired or overwhelmed. The same concept might even be used to measure engagement levels of students, to determine how to adapt learning materials.

Dr. Lotte doesn't want to make predictions about when BCIs, whether invasive or non-invasive, might see wider adoption. But he's noticing BCI start-ups pop up more regularly. "BCI research has become a hot topic in the last few years," he said. "Many labs and companies are working on it, but so far it's not yet reliable."

Dr. Schurger agrees. He warns about the hype, but nevertheless thinks the field is advancing. "Use of invasive BCIs will increase in the next five to ten years," said Dr. Schurger. "For medical use we're likely to see major activity during this period."

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