Technology-Mediated Telepathy: A Natural Language Brain-Computer Interface

Anand Kulkarni, Mathematics / Physics, anandk@berkeley.edu
Kevin Simler, EECS / Philosophy, ksimler@berkeley.edu
Alex Storer, EECS / Cognitive Science, cirrus@berkeley.edu
Maryam Vareth, EECS, maryamv@berkeley.edu
University of California, Berkeley

ABSTRACT

We present a new model for a communication interface between the human brain and a computer. The neurological mechanisms of thought and language in the brain are at present poorly understood. By contrast, the basis of motor activity in the brain is relatively well-known. Our research involves reading the motor signals generated by the human brain while communicating naturally and translating them in real-time into verbal speech. We choose to work with sign language for the purpose of easily reading signals, but this work serves as a proof-of-concept for motors signals from any language provided sufficiently high imaging resolution is obtained. Interestingly, recent work in animal studies suggests that over time the need for corresponding physical action to take place can be eliminated entirely, meaning that communication will transpire silently by using the signals themselves.

KEYWORDS

Brain-computer interface, BCI, EEG, intended motor action, planned motor action, natural language interface

INTRODUCTION

Because brain imaging systems to date, including EEG, have been unable to identify activity generated by patterns of human thought or language in the brain, efforts at developing systems to communicate in natural-language has been written off as impossible. Because the signals generated by thought are so weak and the biological mechanisms are poorly understood, gathering these signals with EEG was demonstrated to be an infeasible means of gathering data from the brain [**1**].

Work to date has instead focused on reading signals associated with imaginary motor activity unrelated to linguistic communication. One typical system allows users to navigate a menu by performing a mental computation or imagining motion of the left arm, right arm, left leg, or right leg respectively to indicate a choice **[2]**. Although the motor signals associated with imaginary motion allow users to communicate, these systems are suboptimal. Users must train extensively to learn to communicate using the devices associated with the system and operate relatively slowly due to the limited number of choices available at any given time.

Instead, we present a design for an EEG-based system that permits users to communicate naturally in a language that is familiar to them. Although we cannot read signals associated with the direct generation of language, we are able to read signals associated with corresponding necessary motor actions. With sufficiently high resolution, a brain imaging system could in theory distinctly identify the position of the lips and tongue during speech by examining brain activity. This information can then be translated into computer- or human-legible text or speech. Unfortunately, because motor activity of the lips during speech is fairly precise and subtle, the resolution required would be very advanced. As current imaging technology does not offer such a resolution, we propose to demonstrate the feasibility of this concept by examining an equivalent system – sign language.

Recent achievements in animal studies using invasive electrodes to take readings suggest that neural signals associated with *intended* motor action can suffice to activate a brain-computer interface. It remains to be seen whether or not readings from intended motor action are sufficient to distinguish using EEG, and whether or not the strength of these signals will be improved with user adaptation to the system. If so, the system will be able to translate the intentions of the user to communicate directly into speech without the need for the corresponding physical activity to take place.

This work intends to serve as a proof-of-concept that with sufficiently high resolution imaging, motor activity associated with verbal speech could be translated into computer-comprehensible format.

TECHNOLOGY

Users are to be wired to a multi-electrode EEG skin cap. This apparatus will connect to a PC running BCI2000, freely available general-purpose BCI control software. Users of the system will be asked to execute a series of signs in sequence. The EEG potentials generated will be recorded and analyzed in real-time by processing algorithms that account for variation in signal strength and duration. The software attempts to match these signals with a database of previously recorded signals from the same user to uniquely identify the word the user is generating. The identified words are then to be mapped to an output device such as a screen or speech synthesizer.

EEG was chosen as the basis for interfacing over other imaging methods despite having low spatial resolution because it permits real-time access to signals and requires relatively low resources. The primary challenge with this method involves the resolution problem and making distinct identification of signals associated with signs; a number of characteristics of our protocol enhance the probability of correct sign identification. The words signed by users are limited to a vocabulary of twenty physically dissimilar signs which are likely to generate distinct signals. Canned speech-recognition algorithms will be used to assist in signal analysis to account for waveform variation in the signals generated.

IMPACT ANALYSIS

The most immediate beneficiaries of such a system are patients with "locked-in syndrome" or other disabilities who are unable to communicate through traditional means. A noninvasive brain-computer interface will allow these patients to communicate reliably without learning to operate unfamiliar systems or undergoing the risk of brain surgery for implanted connections.

Further benefits can accrue to able-bodied users if the technology advances sufficiently. Interest in developing more efficient man-machine interfaces has existed since the development of rudimentary brain imaging systems in the 1950s. A silent, "telepathic" interface between a human and a computer has the potential to revolutionize the means by which humans interact with computers in every way. Instead of interacting via traditional interface methods such a a keyboard, users could simply imagine speaking a request to the computer and it would appear on the screen. In addition to being more rapid, it would be useful in situations where communication is necessary but overt speech or action is impossible. Additional technology will be necessary, but our work provides a proof-of-concept demonstrating that such an interface is viable.

Additionally, the development of our system in particular will answer a number of long-standing open questions in cognitive neuroscience, for example, whether or not the intended motor action recorded from single-electrode implants in animals is equivalent to imaginary motor action recorded via EEG in humans.

INNOVATION

Reading natural-language signals from the brain has been written off as implausible due to the difficulty in obtaining signals associated with language. We elect instead to read motor signals associated with language, a novel approach. Further, our choice of sign language as a medium for natural-language communication is, as far as we know, unique in the literature published to date.

This paradigm stands out strongly from other means of brain-computer interface currently under development. One alternate branch of research involves invasive implants to develop control of a mouse cursor with the motor cortex **[3]**, another uses selection of individual words from a menu by imagining actions **[2]**, and a third uses the P300 "recognition" signal to provide binary input to a computer **[4]**. Using a natural-language interface permits much more freedom in interaction with a computer and other humans than any of these three, particularly for patients who have lost their capacity for speech.

Our research utilizes technology that has existed since the 1950s to achieve an astounding interface.

DEVELOPMENT TIMELINE

Background research and exploratory work has been going on since summer of 2003. Design of the system and development of a viable protocol occurred over the past six months. We are currently in negotiations to obtain lab space to implement the initial proof-of-concept. Assuming no delays occur, we will complete extensive testing with human subjects to establish a usable vocabulary range and set up the translation system by May 2004. Ideally, completion of an advanced proof-of-concept system is expected to occur by the end of summer.

We expect our work to have progressed by mid-April to the point where a rudimentary demonstration of the communication technology will be possible with a very small number of words. Development will proceed simultaneously with user training and selecting a small number of usable signs, and work with Matlab and the BCI2000 software to develop the corresponding translation algorithms.

ACKNOWLEDGMENTS

This work arose indirectly from projects conducted in the Bioengineering 190A course "Introduction to Bioastronautics Research" at UC Berkeley. We are grateful to course instructor Camron Gourginpour for his ongoing support and advice during the development of this project as well as the advice and material assistance given by Dr. Thomas Budinger of the UC Berkeley Department of Bioengineering, without whom this project may not have gotten off the ground. Most importantly, we acknowledge the design efforts and significant contributions of Laurent Menut, MCB '04. His contributions to the development of our idea are very real, but career obligations prevented him from continuing with our research.

REFERENCES

[1] Fujimaki, N., et al. "Event Related Potentials in Silent Speech". *Brain Topography.* Summer 1994.

[2] Obermaier, B., et al. "Information Transfer Rate in a Five-Class Brain Computer Interface". *IEEE Trans. on Neural Sys.* September 2001.

[3] Kennedy, P. R., et al. "Direct Control of a Computer from the Human Central Nervous System. *IEEE Trans. on Neural Sys*. June 2000.

[4] Bayliss, J., Ballard, D. "A Virtual Reality Testbed for Brain-Computer Interface Research." *IEEE Trans. on Neural Sys.* June 2000.