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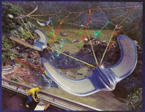

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by Kevin M. Berry

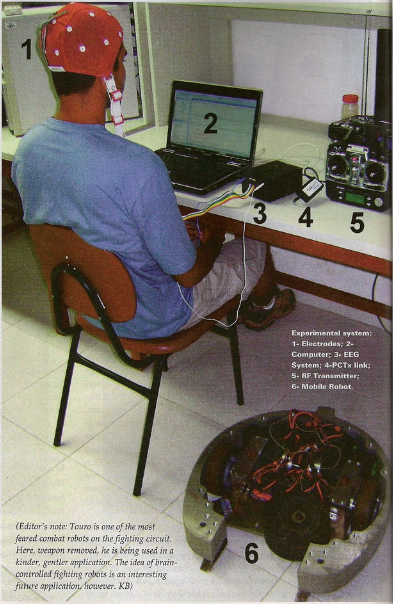
Activation of a mobile robot through Brain Computer Interface

When to replace the keyboard

Editor's Note: Professor Marco Antonio Meggiolaro, of the Pontifical Catholic University of Rio de Janeiro, Brazil, along with two of his students, Alexandre O. G. Barbosa, and David R. Achanccaray, presented a paper on Robotic Brain Computer Interfaces at The 2010 IEEE International Conference on Robotics and Automation (ICRA2010) which was held in Anchorage, Alaska, May 3 - 8, 2010. (http://icra2010.grasp.upenn.edu) In this article, Robot summarizes this significant and deeply technical presentation.

The development of interfaces between humans and machines has been an expanding field in the last decades. It includes several interfaces using voice, vision, haptics (tactile feedback), electromyography (muscle measurements), electroencephalography (EEG) (brain measurements), and combinations among them as a communication support. A system that analyzes brainwaves to derive information about the subjects' mental state is called a Brain Computer Interface (BCI).

People who are partially or totally paralyzed or have other severe motor disabilities can use a BCI as an alternative communication channel. BCI systems are used to operate a number of brain-actuated applications that augment people's communication capabilities, provide new forms of education and entertainment, and enable the operation of physical devices. There are



Experimental system: 1- Electrodes; 2- Computer; 3- EEG System; 4-PCTx link; 5- RF Transmitter; 6- Mobile Robot.

(Editor's note: Touro is one of the most feared combat robots on the fighting circuit. Here, weapon removed, he is being used in a kinder, gentler application. The idea of brain-controlled fighting robots is an interesting future application, however. KB)

K-Team Mobile Robotics is a Swiss company that produces high quality mobile robots used in research. The Khepera III has been used in experiments involving direct brain control.

two types of BCI's: invasive, which are based on signals recorded from electrodes implanted over the brain cortex (requiring surgery), and non-invasive, based on the analysis of EEG phenomena, such as wave rhythms, associated with various aspects of brain function.

The most used of such rhythms are related to the imagination of movements of body parts. BCI applications include control of the elements in a computer-rendered environment such as cursor positioning or visiting of a virtual apartment, spelling software, and command of an external device such as a robot or prosthesis. Recent applications in robotics are the control of a wheelchair and the control of the Khepera mobile robot (www.k-team.com).

IMAGINING BODY MOVEMENTS

In their study, the academics developed a non-invasive BCI based on EEG analysis to control a mobile robot. Control is provided through four specific mental activities: imaginary movements of feet, tongue, left arm, and right arm. These activities are correlated with four robot movements, respectively: stop, move forward, turn left, and turn right. The interface classifies the user's mental activity, sending the corresponding command to activate the mobile robot. The user does not need to be able to perform such foot, tongue or arm movements. Just imagining them is enough to activate the robot.

IMPLEMENTATION OF AN ELECTROENCEPHALOGRAPH

An electroencephalograph is a device that records the brain activity through electrodes placed on the scalp. An 8-channel electroencephalograph was especially developed for this work, consisting of a protection circuit, an instrumental amplifier, a right-leg driver, an amplification circuit and an analog-digital converter. To make the system more portable, for example to be used in electric wheelchairs, the developed EEG measures only 4.2-inch × 3.9-inch × 0.8-inch, as shown in Figure 1.

The EEG A/D converter output was connected to a PC notebook, where the digitalized signals are both preprocessed and processed.

PREPROCESSING

Preprocessing is performed in a PC notebook in four steps: noise filtering, spatial filtering, feature extraction and subject-artifact detection. The noise filtering algorithms remove spurious signals and external interferences. Spatial filtering is needed because conventional EEG recordings have a poor spatial resolution. The signals read on the scalp can be viewed as a 'blurred' copy of the original brain's signal locations. This difficulty can be overcome using mathematical and software techniques, by computing the difference between the potential at each electrode site and the average potential of its nearest neighbors.

Feature extraction involves analyzing and categorizing brain waves to sort out those specifically needed to drive the robotic interface. A series of 10 datasets composed of 700 EEG samples from the same subject was used for training, validation and further tests. Each sample was acquired within a period of one second, including information from eight electrodes (channels). The user was asked to carry out 175 trials of each of the four imaginary movements: left arm, right arm, tongue and feet. From this dataset, 400 trials are used for training, 100 for training validation, and 200 for testing.

Actual muscular movements, such as eye blinks, can alter the EEG signals, introducing so-called artifacts in the signals. Most BCIs require such undesired artifacts to be removed from the signals before processing. Each type of artifact has characteristics in time and frequency that make it easily distinguishable from regular EEG signals. After automatically removing such artifacts, the EEG signal can then be processed.

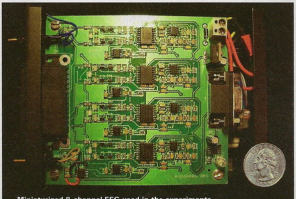
PROCESSING

Once EEG signals have been preprocessed in the computer to generate feature vectors, they are classified as one of the four chosen mental tasks: imaginary movement of the right arm (Right Movement, RM), left arm (Left Movement, LM), tongue (Up Movement, UM, which will be associated to the robot moving forward) and feet (Down Movement, DM, associated to stopping the robot). These mental tasks were chosen due to their accentuated characteristics in brain activity, making them easy to correlate to a desired mobile robot action.

APPLICATION TO A MOBILE ROBOT

To validate the proposed methodologies, the developed BCI is applied to a two-wheeled 120-pound mobile robot. The chosen mobile robot, the middleweight combat robot "Touro" (seen on the opening page without its top cover and drum weapon), was already available in the Robotics Laboratory from the PUC-Rio University. It was already programmed to follow radio-frequency (RF) commands. Therefore no further development was necessary. In addition, such a system is analogous to an electrical wheelchair, one of the possible applications of the BCI. It is driven by only two active wheels using differential drive, and it has enough traction to carry an adult.

The BCI commands are translated to four different movements: turn 30 degrees to the right (RM), turn 30 degrees to the left (LM), move forward 500mm (UM), and stop (DM). (Note that different movements can be defined, even to control completely different systems – the same BCI has been used to move a robotic arm to the right, left, up or down.) The communication with the mobile robot is made through a PCTx module, which receives values from a USB connection



Miniaturized 8-channel EEG used in the experiments.

and translates this data into commands to a Futaba 75MHz RF transmitter that activates the robot. The PC portion of the application is implemented under the MATLAB® environment, including data acquisition from the EEG A/D converter, preprocessing, processing, and sending the commands to the PCTx module. The PC used in the experiment is a 2.2GHz Core 2 Duo notebook.

The system calibration is performed in two steps. In the first step, the user needs to carry out mental activities asked for by the software to calibrate it. First, the user is asked to "trial" (without any body movement) an imaginary movement of his/her feet for eleven seconds (a short beep starts the count and a long beep indicates the end of the acquisition), from which only the last ten seconds are recorded. Then, after a five second pause, the next mental activity (in this case the imaginary movement of his/her tongue) is recorded in the same way, and so on for the left and right arm activities.

TABLE I	Successful Commands	Unclear Commands	Wrong Commands
Modular Multi-Net System Threshold implementation	88.75%	4.5%	6.75%
Hierarchical Model Statistical implementation	91.0%	7.75%	1.25%

This process is repeated until 700 trials are recorded (400 are used for training), taking about 20 minutes including the 1-second trials and 5-second pauses. In the second step of the calibration, the obtained dataset is used to train the classifier. The training of 4 neural networks takes less than 30 seconds in the used notebook. After the training, the system is ready to continuously identify mental activities to control the mobile robot

Two different processing algorithms based on neural networks were developed, called Modular Multi-Net System Threshold implementation (MMN) and Hierarchical Model Statistical implementation (HM). Both were evaluated by asking the user to perform, 100 times, each mental activity, while looking at the mobile robot. Then, the number of successful, unclear (when no mental task is identified) and wrong commands are stored.

Table I shows the results for the mobile robot activation task after 400 attempts, using two developed algorithms. Both implementations result in a very high rate of successful commands, near 90%.

CONCLUSION

A successful BCI was developed, operating with four mental activities for the activation of a mobile robot. The BCI uses intuitive mental activities such as imaginary movement of the left arm to turn the robot left. It was evaluated with 2,000 test trials without the mobile robot and 400 attempts with the robot.

The evaluated methods not only resulted in a high rate of successful commands – about 90% and a low rate of wrong commands – as low as 1.25%. Each mobile robot command was identified in average after 5 trials, which could translate into 5 seconds or less depending on the chosen trial period. Further tests showed time intervals as low as 2 seconds between mobile robot commands with similar hit rates. Another advantage of both methodologies is that the system calibration for a given user takes only about 20 minutes.

The next improvement cycle of their current BCI includes evolving the system into an embedded Brain Machine Interface (BMI). The PC notebook will be replaced by a specially developed 1.6-inch × 1.5-inch × 0.8-inch processing board, capable of performing all neural network calculations. The entire BMI – including EEG and processing unit – should be as small as a 3.5-inch computer hard drive. Such a compact BMI will offer improved portability and user-friendliness, compared with other similar systems being developed by major robotics firms such as Honda.

Professor Meggiolaro is exploring the market potential for an improved version of the system in two ways. One use would be as a very compact and inexpensive EEG for medical applications (for use in ambulances, for instance, with a production cost of about US$125 per eight channels) or as the full BMI for wheelchair or prosthetics applications. He feels there is a viable product niche for either, at a cost one or more orders of magnitude less than current, similar BMIs. ◎

Links

BMI Experiments (Touro); www.youtube.com/watch?v=vxQmjPB9iQM

BMI Presentation at ICRA 2010; www.youtube.com/watch?v=Fjq9YW3OKeY

K-Team Mobile Robotics; www.k-team.com

Pontifical Catholic University of Rio de Janeiro; www.puc-rio.br

For more information, please see our source guide on page 89.

The Khepera mobile robot can easily be held in one hand. Robots of all types, real world and virtual, are being controlled by thoughts alone in diverse experiments worldwide.