Computer-Aided Telepathic Communications

Background:

Electroencephalography (EEG), initially used as a clinical tool, has also been proven to be useful in communications. As early as 1967, a team from a US Air Force Research Lab reported that subjects could be trained to control the amplitude of their alpha waves in EEG and thus send Morse Code using brain waves (Dewan, 1967). Since then, the concept of a "Brain-Computer Interface" (BCI) has been conceived and defined as a "communication or control system in which the user's messages do not depend on the brain's normal output channels" (Wolpaw et al, 2000).

One of the principle uses of such technology is the ability of a disabled person to be able to control limbs with their minds. Researchers at Stanford implanted a microscopic chip into the patients' brains, and were able to obtain enough data to observe the brain patterns behind arm movement, even though the arm movement never took place. After several weeks of intense mental training, the patients could type approximately 15 words a minute just by thinking about it (Santhanam et al., 2006).

Start-up companies such as Emotiv and NeuroSky have been able to create peripheral devices for video-games which interpret input directly from the brain. Emotiv has been even been able to patent their wireless Electrode Headset (Washbon, 2006), a device designed to interface the user with the computer.

EEG is also believed to be an ideal technology for detecting brain patterns related to speech (D'Zmura, 2009). Locked-in patients who cannot communicate verbally or audibly would benefit greatly. Other less medically-related uses would include military uses where soldiers would want to retain absolute silence in a hostile environment. Recently, the U.S. Department of Defense under the auspices of the Multidisciplinary University Research Initiative (MURI) has committed $4 million to teams from Carnegie-Mellon, University of California at Irvine and New York University to its Synthetic Telepathy project (Thompson, 2008).

Recent studies in Brain-Computer Interface related communication have been focused around the differentiation of syllables. In very basic studies of two syllables, researchers have found consistent and distinct recognition of the syllables "ba" and "ku" by studying imagined syllables recorded from patients in three different rhythms (Deng et al., 2010).

The focus of this work will be to test the brain patterns created by some of the 40 phonemes of the English language. It seems logical that since previous studies have indicated that syllables can be accurately interpreted greater than 70% of the time (Deng et al., 2010) strings of phonemes forming words could be consistently interpreted using a readily available speech-to-text server and transmitted anywhere using the ubiquitous wireless technology that surrounds us.

Purpose:

To devise a non-intrusive computer-aided telepathic communication method, using conventional electrodes and phonetic brain pattern interpretations. This project will use EEG to observe measurements from a specific region of the brain known as the Left Frontal Lobe (Broca's Area). This region of the brain is located between the left eyebrow and left ear, slightly above the level of the eye. Whenever one thinks in words (or rehearses what they are going to audibly say), this area is responsible for conducting the associated brain activity.

Hypotheses:

Specific unique brain patterns in the form of spectrograms are hypothesized to accurately represent unique phonemes. It is further hypothesized that these phonemes can be interpreted in real time and translated into audio using a computerized text-to-speech voice. Brain patterns in the form of spectrographs will be acquired using a self-constructed two-channel EEG apparatus.

Procedure:

There are two main procedures in this project:

A. A two-channel EEG was built from components in order to measure the brain activity. Documentation available at the OpenEEG Project was consulted during the construction phase (http://openeeg.sourceforge.net/doc/)
B. Studies were conducted on subjects to obtain brain activity spectrograms related to specific English language phonemes.

A. EEG Construction Procedure:

1. The box containing the main unit was constructed by creating mounting points in a plastic box for the digital receiver board and the metal box containing the analog receiver board. Holes were cut out for five XLR sockets, one serial socket, and power toggle. USB leads were soldered to +/-/GND pins on XLR female connectors.

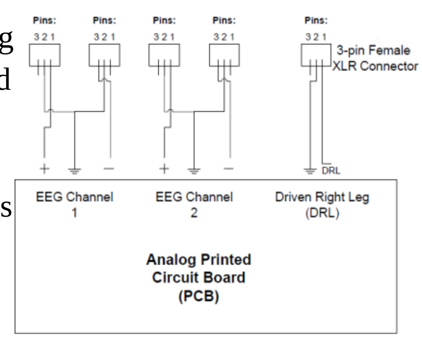

Figure 1: Analog Receiver Board and Connectors

The metal box containing the analog board and digital boards were placed and electrically isolated in the main unit (plastic box). The power toggle, and serial sockets were connected to the digital board. A 34-pin IDC cable was created from a 40-pin floppy drive cable and 34-pin IDC connectors were punched down onto the ends. The digital and analog boards were connected together using the aforementioned 34-pin cable. (See Figure 1)

2. The EEG apparatus was verified by running Electric Guru (open source brain activity software: http://www.realization.org/page/topics/electric_guru.htm) and connecting the EEG to the computer through a 9-pin serial to USB cable. Waveforms were viewed to confirm the proper reception of signals in the expected range for signal reception (3 to 48 Hz). Detected noise was dealt with by verifying grounds and reference connections. Mains Hum (60 Hz) interference was significantly reduced by controlling the testing environment (see below) and ensuring all connections were grounded.

3. Female XLR ended cables were connected to the main unit, which were directly attached to required locations on the analog board via male XLR connectors on the outside of the unit. Shielded audio cable 1.2 meters in length were cut and the shields were grounded. 2-pin audio cables were soldered to the XLR male connectors on appropriate pins.

   With the other end of each shielded audio cable, a 1-pin female RCA socket was soldered. The electrodes connecting to this socket were soldered in place from a piece of wire, a male RCA socket and a piece of 99.5% silver. The electrodes were connected to the main unit via the shielded/grounded XLR cables created for this purpose.

B. Subject Testing Procedure:

1. Test subjects comprised of 9 adults over the age of 18 who had given written informed consent were asked to imagine speaking six specific phonemes. Each phoneme was displayed on a computer screen for one second, and then an interval slide was shown before the next phoneme. Each phoneme was displayed 20 times and a baseline of brain activity was recorded for each phoneme (training dataset). The process was completed a second time to create test data to compare against the reference (test dataset). The data acquisition was completed in a quiet, dimly lit room with no close AC electrical appliances and no interruptions. The phonemes used in the experiment were */w/, /au/, /t/, /s/, /o/, /n/*.

2. Test subjects were prepared by pressing the silver electrodes directly on the skin with conductive 10-20 EEG paste and held in place using sponge and an elastic cap designed for this use. The electrodes were placed in the F7 (Broca's Area) and Fp1 (reference electrode) locations according to the International 10-20 system of electrode placement (Thompson, 2003).

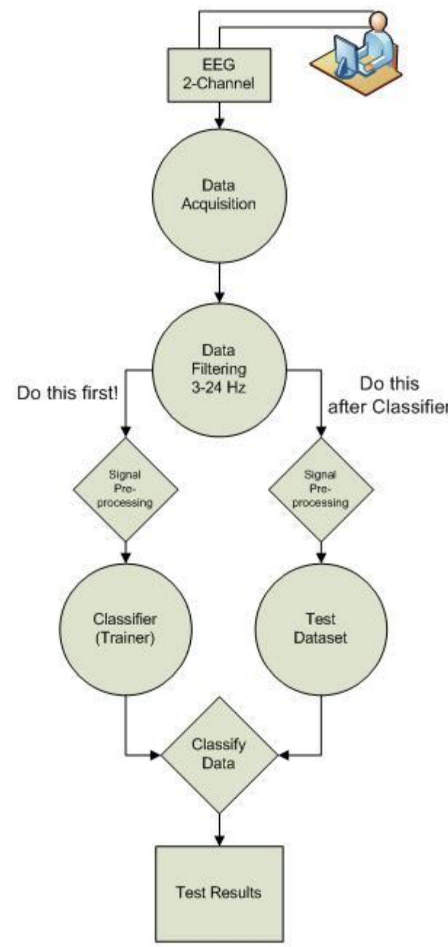

Figure 2: Data Acquisition and Testing Sequence

3. Data was collected using OpenVibe brain computer interface

Open Source software (http://openvibe.inria.fr/). Test datasets were completed twice for each subject using a data acquisition procedure programmed using the OpenVibe development environment.

4. After acquisition, the "test" dataset was compared to the "training" dataset using LDA (Linear Discriminant Analysis). Each member of the "test" dataset was compared to the training dataset to determine the successful detection rate per phoneme. Each of the collected datasets was compared and analyzed offline (the comparisons are made in the OpenVibe environment programmed for this task after the datasets had been recorded during the acquisition phase). Simulation based epochs (chunks of the datastream) were analyzed using FFT (Fast Fourier Transformation) in the preprocessing step before the resultant streamed matrix was sent to the Classifier Trainer (from the training step) or Classifier (the testing step). See Figure 2.

Results and Observations:

The results for the 9 subjects are shown in Table 1. These results reflect the % recognition by the Classifiers for each phoneme in each indicated frequency range summarized for all participants.

Table 1: Rate of Recognition (%) for Phonemes in Various Frequency Bands

	Frequency (Hz)								
Phoneme	3-8	8-13	13-18	18-23	23-28	28-33	33-38	38-43	43-48
/W	9.44	11.67	13.33	12.78	15.56	10.56	7.78	7.78	18.89
/aw	**25.00**	21.67	**27.78**	11.11	11.11	13.33	16.11	18.33	8.89
/T	6.67	21.11	7.78	9.44	6.67	11.67	**29.44**	10.56	6.11
/S	17.78	21.67	17.78	10.56	13.33	11.67	8.33	7.22	11.11
/uh	17.22	22.78	13.89	5.56	22.22	17.78	**27.22**	**27.78**	**32.22**
/N	**32.78**	10.00	**27.22**	**54.44**	**43.89**	**49.44**	23.89	**41.67**	**42.78**

Note that the values are bold and in red where the rates of recognition reach statistical significance with a 95% confidence interval using a Student's one-sided t-test. Rates of Recognition were compared against the baseline rate where the result is entirely random – 16.7%.

Significant values and recognition of phonemes occurred for the /N phoneme in nearly all the selected frequency bands (3-8 Hz, 18- 33 Hz and 38- 48 Hz). The /uh phoneme appeared in the 28-48 Hz range. The /aw phoneme was significant in the 3- 8Hz and 13- 18Hz ranges. /T was found to be significant in the 33-38 Hz range. (see Table 1)

Conclusions:

A system of determining phonemes consistently from a two-electrode EEG was not completely successful. The data does not support the consistent ability to read phonemes from the F7 locale in the 10-20 scheme by itself using the current system. Some phonemes were significantly apparent in more than one band, but the system as presented cannot be used for speech as only 4 of the 6 phonemes could be adequately detected.

What now needs to be investigated is whether individual phonemes are only significantly determined in specific frequency bands or whether they should be significant across the entire frequency spectrum known for human speech (3- 48 Hz).

Whether the use of a two-channel appliance affected the results is a matter of speculation. Future work would need to determine whether having a 6-channel (or more) system additionally covering Wernicke's Area, also known for higher language functions (Callies, 2006), would improve the detection of phonemes.

In this study, no attempt was made to "train" the user by giving real-time feedback to whether their thinking was matching the phoneme being detected. The study was undertaken to find a system that does not require training, as many of the locked-in patients who need such a system would find training difficult.

The use of Fast Fourier Transformation in the pre-processing of detected signals could also be investigated. One very positive outcome of this experiment is that scenarios were designed to acquire, train and test for brain signals in the OpenVIBE environment. In particular, the connection to a MATLAB server developed for testing various pre-processing methods not available (eg: the Hilbert Huang Transform) makes future work in this area less time-consuming and more productive.

This experiment was important for determining if a simple non-invasive EEG detection device could be used for the detection of phonemes. Such work is important in determining the requirements for building a non-invasive and inexpensive to deploy machine that allows for non-verbal communication.

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