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Mapping Brain Activity Using Wearable EEG Sensors for Mobile Applications

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Abstract- Brain computer interface (BCI) has been used to map brain activity. This mapping is further used for signal classification to generate various control signals. Electroencephalography (EEG) is used to record electrical fields that represent the brain signals and are generated due to the local brain function. EEG recordings for medical diagnosis and prognosis purposes require a specialized laboratory setup. Recently wearable EEG sensor headsets have become commercially available that can be easily setup to record brain activity non invasively. In this paper brain activity mapping using these wearable sensors has been presented. The mapping is performed on a mobile device by connecting the scanner directly to the mobile device over a wireless bluetooth interface. The processing capability of current day smart phones can be effectively used to develop a completely mobile EEG scanner. A limitation of these headsets is the number of sensors available for recording brain signals. Specialized signal processing algorithms can be used to produce clinically acceptable EEG recordings using these headsets. An inherent advantage of using BCI with these wearable sensors is providing support to disabled persons in a non medical facility, e.g. home. It can also be used to provide a platform for remote health monitoring of brain related diseases and rehabilitation of patients.

Keywords: Brain computer interface, Remote health monitoring, Wearable sensors, EEG

1. Introduction

Electrical signals generated due to brain activity are a useful way of looking at the brain function. Different imaging modalities are currently in use to study the structure and function of human brain. The neurons that make up a major part of our brain, the central nervous system (CNS), are responsible for processing the information gathered using various sensory organs (e.g. our vision and hearing) Wolpaw et al. (2002). This information processing generates control commands for the peripheral nervous system (PNS) and produce motor control. The electrical activity generated in the process is a good indicator of healthy brain function. Current research has been focused on understanding the underlying working of the human brain using various tools and techniques. Major advancements have been made since the advent of advanced imaging techniques such as magnetic resonance imaging (MRI) and the phenomenal increase in the information processing capabilities now available at our disposal.

Functional MRI (fMRI) is currently the most widely used methodology to study brain function. Other

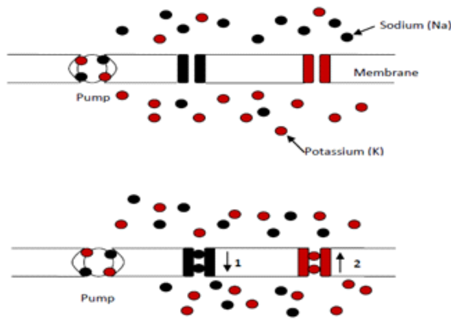


Fig. 1. Inside and Outside of membrane (a) Equilibrium State: More *K* ions inside the membrane, the Na and K gates are closed (b) Excited State: Na and K gates open. First there is an influx of Na ions (1) causing the membrane potential to rise which is followed by out flux of K ions (2).

imaging modalities such as Positron Emission tomography (PET) and single positron emission tomography (SPECT) are also used. fMRI has demonstrated the best image contrast and resolution among different modalities. The only limitation of this technique is the temporal resolution, since fMRI relies on blood oxygenation level (BOLD) to generate contrast. This is an indirect measure of brain activity. Electroencephalography (EEG) is a more direct measure of brain activity and provides better temporal resolution than fMRI. But strictly speaking EEG is not an imaging modality, although it has been used to generate functional images of the brain in some studies. In this study EEG is demonstrated as an imaging technique. A combination of fMRI and EEG can be used to produce excellent spatial and temporal resolution Owen and Martin (2008). The limitation in this case is the clinical setup required to produce such a scan. MRI in particular is expensive and not very widely available. Efficiently using EEG for brain activity mapping using wearable sensors would generate enormous applications of the brain computer interface (BCI) systems in clinical and non-clinical applications.

The rest of the paper is organized as follows: An overview of the EEG signals and its use in BCI is presented in Section 2. Section 3 deals with EMOTIV EPOC EEG sensor used in the experimentation and how the brain activity is mapped on mobile devices. Experimental results and the developed mobile application for EEG brain activity mapping id discussed in Section 4 followed by conclusion in Section 5.

2. Background

EEG has been used to study brain function for a long time. The early focus had been on detection neurological disorders such as Epilepsy. These days EEG is finding a wider use in the field of BCI.

2.1. Electroencephalography (EEG)

Electric field generated due to brain activity is detected using EEG. Neurons communicate using ionic conduction that result in generation of action potentials (AP). A resting neuron has usually a charge of -65mV. When neurons interact due to a sensory input the neuronal membrane polarizes. In the process the potential difference at the neuronal membrane (between the inside and outside of neuron) raises, usually up to 40mV. This process is known as action potential generation.

An illustrative mechanism of how these ions move is shown in Fig. 1. Sodium and potassium ions are the main ionic channels involved in action potential generation. The flow of these ions is controlled by ionic pumps (shown as red and black openings in Fig. 1). The opening and closing of these ion gates control the membrane voltage Tatum (2007). The behavior of these gates has been modeled by non linear equations based on empirical observations presented by Hodgkin and Huxley Pospischil et al. (2008).

Fig. 2. EMOTIV EPOC headset (courtesy emotive.com).

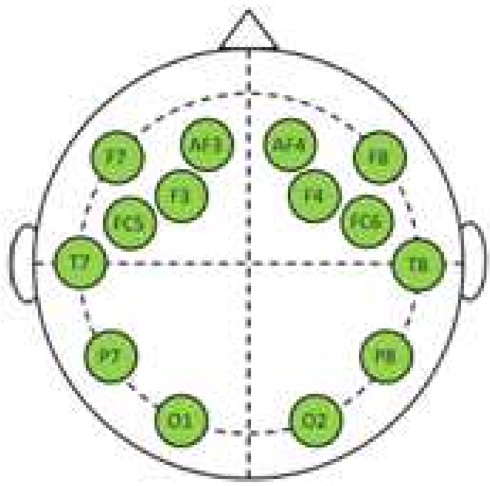


Fig. 3. EMOTIV electrode placement on 10-20 electrode System.

The purpose of EEG is to record the electric fields generated due to the conduction of ionic currents. Different types of EEG recordings are in clinical use. External electrodes placed on the skull are the most comfortable way of recording brain activity. The method does suffer from low signal to noise ratio (SNR) since the fields are greatly attenuated after passing through the skull Wolpaw et al. (n.d.). Advances in signal processing techniques and availability of specialized hardware have made it possible to process the recorded data at the skull. This processed signal quality has been found to be useful in clinical and non-clinical applications.

2.2. Brain Computer Interface (BCI)

Non-invasive EEG has been widely used for the purpose of providing an interface between the brain activity and a computer device. BCI has been investigated has a potential solution for providing support to people suffering from neurological impairments affecting motor function Allison and Wolpaw (2007). The potential applications and research activity had been limited in the past. The main reason for this limitation is the quality of EEG signal recorded by electrodes placed on the skull. Although implanted electrodes have been used in a few applications improving the SNR and hence the accuracy of a BCI, but the user discomfort in implanting electrodes has always been a limitation Serruya et al. (2002).

Recent innovation in this field has resulted in specialized headsets that are easy to use and give good

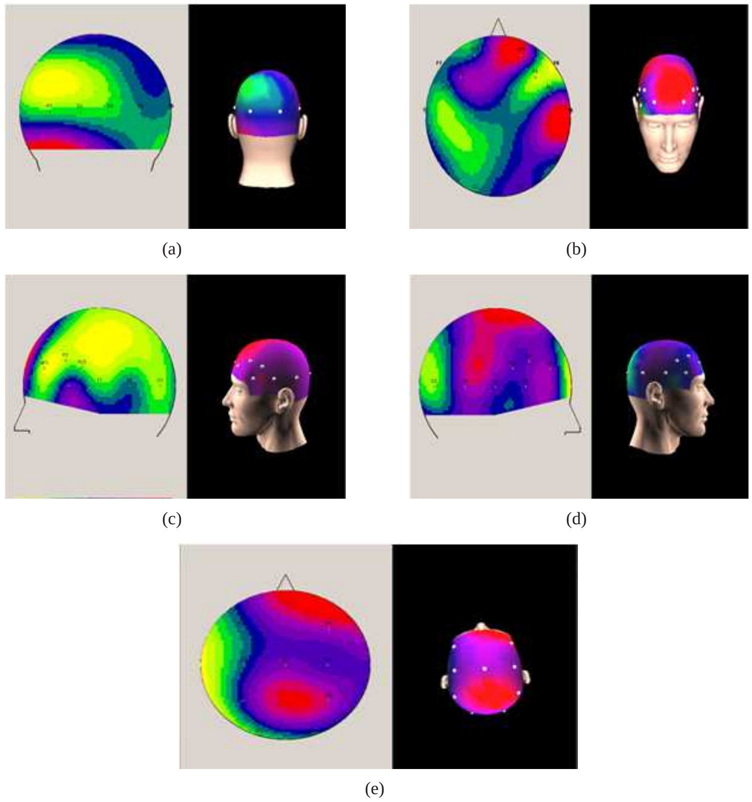
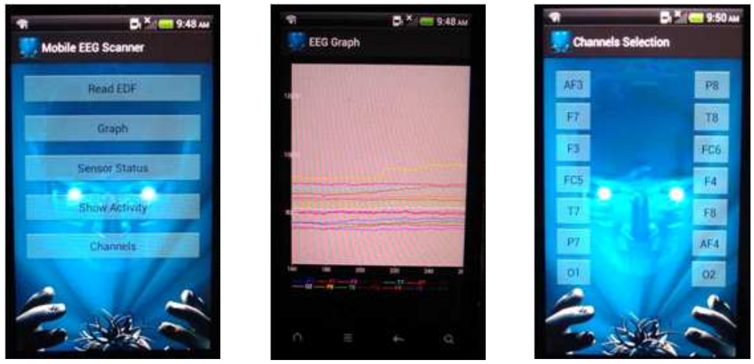


Fig. 4. Brain activity maps with relevant electrodes (a) Back view (b) Front view (c) Right view (d) Left view (e) Top view.

quality of recorded signals. The research activity has also picked up and the potential applications have found a many fold increase. A brain computer interface aims at acquiring data that gives a picture of the underlying brain activity. The recorded data is classified using various features of interest, which is then used as control signals for a computer device Krusienski et al. (2006); Zhang (2001). Three type of EEG based BCI's can be distinguished depending on type of Event Related Potential (ERP) used like P300, steady-state visual evoked potential (SSVEP), steady state evoked potential steady-state somatosensory evoked potential, motor imagery, slow cortical potentials Bin et al. (2009); Combaz (2009); Martinez et al. (2007). A BCI provides an alternate communication channel to the brain, where the normal channels have normally depended on the motor function. The BCI has been successfully demonstrated for simple applications such as cursor control Leuthardt et al. (2004) and typing applications as well as for esthetic applications like prosthetic arm for self feeding Velliste et al. (2008) and mind controlled wheel chair Sellers et al. (2010).

The advent of commercial wearable sensors has opened the field of BCI to other exciting application areas such as the gaming industry. This is a wider implication of more research funding and hence further development of EEG data recording systems. A recent example is the introduction of 5 channel dry sensor EMOTIV headset. The introduction of dry electrode channels promises to have more reliable EEG recordings and a much better placement of electrodes.



(a) (b) (c)

Fig. 5. Screenshots of mobile application developed for brain activity mapping (a) Mobile EEG Scanner (b) EEG Graphs (c) Channel Selection.

3. Brain Activity Mapping

The electric fields recorded using EEG can be used to map the brain activity directly. These signals are the most direct measure of looking at the brain function. In this work brain activity is mapped on a mobile device. The complete system of a wearable sensor and a mobile processing unit has the advantage of greater mobility. This has the potential to use BCI in areas not used in traditional BCI applications. A successful classification of brain activity using mobile devices could be used to realize brain to brain communication.

3.1. EPOC Headset

Emotiv EPOC (www.emotiv.com) headset is a 14 channel device that can be used to record non invasive EEG signals. The biggest advantage is this headset is the ease of setting up the data acquisition of EEG data. This is one in many in the line of commercial headsets now widely available. Wearable sensors such as these are pushing the limits of BCI applications which are now finding wider acceptance and accessibility. The headset is shown in Fig. 2.

The headset uses the 10-20 electrode placement system. These electrodes locations are in use (AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4). A typical 10-20 system is shown in Fig. 3. This headset only used 14 channels but provide a good spatial resolution and coverage of areas in the frontal, peripheral, occipital and temporal areas of the brain.

A typical placement of electrode locations used by EMOTIV is shown in Fig. 3. Two reference electrodes are also used in addition to the 14 sensors. This wireless headset uses bluetooth to transmit recorded data, giving enhanced mobility to the user. Single electrode headsets (www.neurosky.com) and band like headsets have also become available. Many applications have been developed on mobile devices that use these headsets and provide great usability e.g. sorting out the music playlist on a mobile. The quality of signal and spatial resolution for EMOTIV headset is found to be better than single channel headset and hence is explored for medical applications where a compromise on signal quality is not acceptable.

3.2. Brain Activity Maps

Brain activity maps are generated from the EEG recorded data for various visual tasks. The user is asked to perform a reading task and also to look at a computer screen during data acquisition. Various sensory organs are activated during the task that is manifest in the recorded electrical activity.

A block diagram of the brain activity mapping system is shown in Fig. **??**. The acquisition client is used to record real time data from the EPOC headset while the user performs the assigned task *i.e.,* read or look.

Initial signal processing is applied to the recorded data before using it to generate 2D and 3D maps of the activity. The simulation of the system is performed using OpenViBE Renard et al. (2010). Event related potentials (ERPs) are generally used for the purpose of signal classification in typical BCI systems. The mapping can be further improved by employing these events related potentials such as steady state visually evoked potentials.

4. Results

The brain activity maps present a color coded representation of the neuronal activity taking place in the brain and recorded using EEG. Fig. 4 shows the brain activity maps. The electrode positions used in each view are shown on the figure. These 2D views can be combined to generate a 3D map that allows playing the recorded data as a video. These images can be used to study the brain function that can complement the MRI based studies.

The front end of the mobile application is shown in Fig. 5. The application is developed using android platform. Functionality has been provided to display EEG data as line graphs and channel selective display of data. The application can be further enhanced to perform detection of abnormal activity locally at the mobile unit. The processing capability of current day mobile devices certainly supports such kind of preposition. This can certainly go a long way in further enhancing the usability of BCI systems.

An inherent advantage of the setup presented is the remote monitoring of patients suffering from brain related diseases. The headset provides a user friendly setting up environment and wireless communication using bluetooth. The recorded data can be transmitted to a central server where it can be logged and processed to generate reports for clinical purposes. Any detection of abnormal activity or stroke can be used to raise alarms.

Locked in patients, that are suffering from motor function disability but have a properly working central nervous system could the greatest beneficiary of these systems. It has been shown that such people have a very normal brain function in terms of generating neuronal commands. This neuronal activity recorded using EEG is used for generating BCI commands to provide rehabilitation to such people.

5. Conclusions

The commercial off the shelf availability of EEG headsets has resulted in an increased interest of the research community in the field of BCI. The clinical setup required to acquire EEG signals is no longer required. Although these headsets have made it possible to record EEG in a more relaxed and home like situation, the quality of the signals is not as good as produced by EEG recorded from clinically used electrode caps. The signal quality is obviously of a lesser quality when compared to invasive EEG. The limitations might restrict the use to these headsets in clinical setup where prognosis and diagnosis of a neurological disorder is required. But the accuracy of results produced has shown the potential of using these EEG recordings to classify brain function. This has found use in gaming industry where addition of brain controlled commands to the widely used gesture controlled environment promises to revolutionaries the current state of the art. The results presented here shows that the brain activity can be mapped using a mobile device with the help of these wearable sensors that can be used in BCI controlled application. This has a wider application in remote health monitoring of brain related diseases. The improved signal processing capabilities of the mobile devices and use of dry electrodes will further enhance the usability of such systems. Future work will be focused on development of specialized event related signal classification algorithms for mobile devices to produce highly accurate BCI systems. Learning methods will be incorporated so that the system becomes adaptive to a user to produce even better results.

References

Allison, B. and Wolpaw, J. R. (2007), ‘Computer interface systems: Progress and prospects’, *Expert Review of Medical Devices* **4**(4), 463–474.

Bin, Guangyu, Gao, X., Yan, Z., Hong, B. and Gao, S. (2009), ‘An online multi-channel ssvep-based brain-computer interface using a canonical correlation analysis method.’, *J. of Neural Engineering* **6**(4).

Combaz, A. E. A. (2009), Feature extraction and classification of eeg signals for rapid p300 mind spelling.

Krusienski, D. J., Sellers, E. W., Cabestaing, F., Bayoudh, S., McFarland, D. J., Vaughan, T. M. and Wolpaw, J. R. (2006), ‘A comparison of classification techniques for the p300 speller’, *Nature* **3**(4), 299–305.

Leuthardt, E. C., Schalk, G., Wolpaw, J. R., Ojemann, J. G. and Moran, D. W. (2004), ‘A braincomputer interface using electrocorticographic signals in humans.’, *J. of Neural Engineering* **1**(2), 63–71.

Martinez, P., Bakardjian, H. and Cichocki, A. (2007), ‘online multicommand brain-computer interface with visual neurofeedback using ssvep paradigm.’, *Computational Intelligence and Neuroscience* pp. 13–13.

Owen, A. M. and Martin, R. C. (2008), ‘Using neuroimaging to detect awareness in disorders of consciousness’, *Functional Neurology* **23**(4).

Pospischil, Martin, Toledo-Rodriguez, M., Monier, C., Piwkowska, Z., Bal, T., Frgnac, Y., Markram, H. and Destexhe, A. (2008), ‘Minimal hodgkin-huxley type models for different classes of cortical and thalamic neurons’, *Clinical Neurophysiology* **99**(4-5), 427–441.

Renard, Y., Lotte, F., Gibert, G., Congedo, M., Maby, E., Delannoy, V., Bertrand, O. and Lcuyer, A. (2010), ‘Openvibe: An open-source software platform to design, test and use brain-computer interfaces in real and virtual environments.’, *Teleoperators and Virtual Environments* **19**(1).

Sellers, E. W., Theresa, Vaughan, M. and Wolpaw, J. R. (2010), ‘A brain-computer interface for long-term independent home use’, *Amyotrophic Lateral Sclerosis* **11**(5), 449–455.

Serruya, M. D., Hatsopoulos, N. G., Paninski, L., Fellows, M. R. and Donoghue, J. P. (2002), ‘Brain-machine interface: Instant neural control of a movement signal’, *Nature* **416**(6877), 141–142.

Tatum, W. O. (2007), Handbook of eeg interpretation, *in* ‘Handbook of EEG Interpretation’.

Velliste, M., Perel, S., Spalding, M. C., Whitford, A. S. and Schwartz, A. B. (2008), ‘Cortical control of a prosthetic arm for self-feeding.’, *Nature* **453**(7198), 1098–1101.

Wolpaw, J. R., Birbaumer, N., Heetderks, W. J., McFarland, D. J., Peckham, P. H., Schalk, G., Donchin, E., Quatrano, L. A., Robinson, C. J. and Vaughan, T. M. (n.d.), ‘Brain-computer interface technology: A review of the first international meeting’, *IEEE Tran. on Rehablitation Engineering* (2).

Wolpaw, J. R., Birbaumer, N., McFarland, D. J., Furtscheller, G. P. and Vaughan, T. M. (2002), ‘Brain-computer interfaces for communication and control’, *Clinical Neurophysiology* **113**(6), 767–791.

Zhang, T. (2001), ‘An introduction to support vector machines and other kernel-based learning methods.’, *The AI Magazine* **22**(2).