A Cross-Platform Smartphone Brain Scanner

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Abstract

We describe a smartphone brain scanner with a low-cost wireless 14-channel Emotiv EEG neuroheadset interfacing with multiple mobile devices. This personal informatics system enables minimally invasive and continuous capturing of brain imaging data in natural settings. The system applies an inverse Bayesian framework to spatially visualize the activation of neural sources real-time in a 3D brain model or to visualize the power of brainwaves within specific frequencies. We describe the architecture of the system and discuss initial experiments.

Author Keywords

EEG, brain scanner, smartphone, personal informatics, BMI

ACM Classification Keywords

H.5.2 [Information Interfaces and Presentation]: Miscellaneous

General Terms

Design, Measurement

Introduction

In recent years personal informatics tools and applications have gained increased attention. More recently the trend towards self-monitoring appears to be moving from an

early adopter phenomenon to gain more wide-spread appeal. A lot of attention has been on simple devices to capture data about physical activity or sleep patterns. However, better understanding of the intricate relations between our brains and behaviors could be a key to future improvements in well-being and productivity, but in the personal informatics domain less attention has been on continuous monitoring of brain signals.

The main reason has been that traditional functional brain imaging techniques including fMRI and PET typically rely on complex, heavy hardware that offer limited comfort and mobility for the user. Thus the understanding of brain activity in real-life settings has been limited, as it has mainly been possible to measure brain activity in laboratory settings, which may induce largely unknown biases. In particularly for studies of emotion and social cognition [2] this may be problematic. The ability to monitor brain activity continuously under naturalistic conditions to study how we perceive our surroundings in mobile real-life settings have a set of obvious applications and advantages [2].

In this paper we describe a minimally invasive brain monitoring system offering real-time brain state decoding and 3D cortical activity visualization on multiple low-cost mobile device form factors (from smartphones to tablet devices). The system can be used to continuously record brain states, e.g. emotional responses, and the 3D visualization or brainwaves within specific frequencies can be used for simple bio-feedback.

Applications of continuous bio-feedback is interesting in the context of personal informatics. It has been shown that such bio-feedback may lead to improvements in behavior, reaction times, emotional responses, and musical performance. Within the clinical domain it has been shown to have a positive effect on attention deficit, hyperactivity disorder, and epilepsy [4]. For such applications a low-cost and easy-to-use brain monitoring system enabling mobility can be beneficial.

The adoption of Brain Machine Interfaces (BMIs) has so far been limited by the cost of the EEG equipment, cumbersome setup, and low portability. Also advanced analysis algorithms have traditionally not been applied in real-time, limiting the potential of BMIs to decoding of simple states. The presented system addresses those issues by focusing on a low-cost consumer grade solution (an off-the-shelf neuroheadset combined with a smartphone or tablet device) with complex real-time analysis on the portable device, not limiting the use-cases to the classical stationary setup. The implemented modules constitute a flexible framework enabling various Brain Machine Interfaces to be built utilizing affective and cognitive states of various complexity as well as enabling mobility during EEG monitoring.

Smartphone Brain Scanner

The Smartphone Brain Scanner provide multiple functions including stimulus delivery, data acquisition, logging, brain state decoding and 3D brain activity visualization. In the current system a wireless Emotiv EPOC 14 channel neuroheadset is used to acquire the raw EEG data with a sampling rate of 128 Hz. All subsequent processing is performed directly on the mobile device by custom-made software. In the current configuration the software is able to perform real-time brain state decoding as well as provide bio-feedback to the user through a 3D rendering of the active cortical EEG sources.

The 3D brain model contains 1028 vertices and 2048 triangles and the user can interact with the 3D model on

the device using touch gestures. The source activity is reconstructed using a low resolution brain electromagnetic tomography (LORETA) approach, performed in 16 samples window, resulting in the snapshots update rate of 8 Hz. Based on the source activations, a spectrogram can be calculated using Fast Fourier Transform performed on all vertices on the 16 samples window resulting in a spectrogram from 0 to 64 Hz with a 1 Hz resolution. The brain activity is rendered using ranges of RGB color values, providing a performance of approximately 30 fps and fluent touch-based interaction with the 3D model.

Figure 1: The Smartphone Brain Scanner running on a Linux-based EXOPC tablet (top left), the Emotiv neuroheadset, Android-based Acer tablet (top right), Android-based HTC smartphone (bottom left), Maemo-based N900 smartphone (middle), and a MeeGo-based N950 smartphone (bottom right).

In a configuration using the Nokia N900 smartphone the system has a delay of less than 150 ms. between the signal emerging in the brain and being visualized on the smartphone. The delay depends on the amount of processing enabled and the mode of operation. The system implementation is based on the Qt framework and benefits from the cross-platform support of multiple

hardware platforms (smartphones, tablet devices, netbooks, and PCs) that are based on the Linux operating system. Thus the system runs on multiple platforms, including Maemo/MeeGo based smartphones, Android-based smartphones and tablet devices, as shown in Figure 1.

Discussion
The main challenge for the mobile real-time brain scanner is the power consumption on the mobile device (e.g. smartphone) and the neuroheadset, which both put a constraint on the duration the system can be used. We have carried out experiments with continuous local logging of EEG data, which allowed 7.5 hours of usage. However, with online data analysis only 3.5 hours of usage is possible.

To validate the brain state decoder we examined its ability to distinguish between left and right imagined finger tapping on a single subject. We applied the Common Spatial Patterns (CSP) algorithm combined with linear discriminant analysis (LDA) as it has shown useful for discriminating between different motor tasks [3]. Input data was bandpass filtered 8-32 Hz and focused on the interval 0.75-2.00s after the stimuli, which resulted in an accuracy of 64%. Additionally, we examined if the smartphone brain scanner could distinguish pleasant and unpleasant images based on the EEG recordings representing the subjects affective response. The images were selected from the international affective picture system (IAPS) based on their classes and in accordance to [1]. LDA was used to separate the two classes given input features focusing on the power in the frequency interval 4-48Hz and time interval 100-500ms after stimuli. Six out of eight subjects could be classified with an accuracy above a random baseline model.

To analyze whether the generic design of the neuroheadset is capable of capturing common patterns across the 8 subjects, we reduced the dimensionality using principal component analysis (PCA) and applied a K-means algorithm (N=10) to cluster 8 x 14 ICA independent components based on scalp maps and power spectrum. The results show that 32, 19 and 34 out of 112 ICA components were shared among 8, 7 and 6 subjects respectively – all within 3 standard deviations of the centroids. This indicates an ability to consistently capture common patterns of brain activity across subjects, even when taking into account the less accurate positioning and limited number of electrodes on the neuroheadset compared to traditional EEG caps. While the clustered ICA components do not represent absolute scalp map polarities as such, they indicate common sources of synchronous brain activity, consistent with activities in central, temporal and parietal cortex previously observed to differentiate responses when viewing affective pictures compared to neutral content. The described classifications were carried out offline, although a classification directly on the device is currently in progress.

Conclusions

We have demonstrated that complex reconstruction is possible on multiple mobile device platforms, including 3D reconstruction and spectrograms, and have carried out initial experiments. The wireless system enable complete user mobility and continuous logging of brain activities either for real-time neurofeedback purposes or for later analysis, which are both considered highly relevant for personal informatics applications.

The cross-platform support offers different kinds of brain machine interaction and applications which facilitate personalized interfaces reflecting emotional state or intelligent interaction on different device form factors. The ability to runtime visualize the changes in power from the raw EEG data in a 3D model of activations, may enable localized control of specific brainwave frequency patterns used for training neurofeedback control in brain machine interfaces.

Unlike traditional lab-based EEG monitoring, a major advantage of the wireless setup is that it enables both mobility and for EEG monitoring in natural settings, and thereby enabling continuous monitoring of brain signals for personal informatics applications.

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