# The portable P300 dialing system based on tablet and Emotiv Epoc headset

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*Abstract*—**A Brain-computer interface (BCI) is a novel communication system that translates brain signals into a control signal. Now with the appearance of the commercial EEG headsets and mobile smart platforms (tablet, smartphone), it is possible to develop the mobile BCI system, which can greatly improve the life quality of patients suffering from motor disease, such as amyotrophic lateral scleroses (ALS), multiple sclerosis, cerebral palsy and head trauma. This study adopted a 14-channel Emotiv EPOC headset and Microsoft surface pro 3 to realize a dialing system, which was represented by 4×3 matrices of alphanumeric characters. The performance of the online portable dialing system based on P300 is satisfying. The average classification accuracy reaches 88.75±10.57% in lab and 73.75±16.94% in metro, while the information transfer rate (ITR) reaches 7.17±1.80 and 5.05±2.17 bits/min respectively. This means the commercial EEG headset and tablet has good prospect in developing real time BCI system in realistic environments.**

## I. Introduction

Brain-computer interfaces (BCI) are novel communication systems that enable a direct connection between the brain and a computer through translating brain signals into control signals. BCIs could restore some of the lost communication channels for severely disabled people.

In recent years, since invasive BCIs are implanted directly into the grey matter of the brain during neurosurgery with high risk, non-invasive BCI systems based on Electroencephalogram (EEG) signals are developed quickly because of their safety and convenience, especially the BCI based on P300 wave of visual evoked potentials (VEP)[1]. It has been used widely because it is easy to elicit, consistent and needs little initial training[2, 3]. Many applications based on P300 have been developed, including P300-based speller [4], smart home applications [5], lies detection [6] and sending emails over the internet browsers [7]. One of the most successful BCI applications is p300 speller developed by Farwell and Donchin [8].

However the existing P300-based BCIs have numerous problems and obstacles [9, 10], such as the high cost of EEG acquisition equipment and their lack of mobility. Especially, more progress should be made in resolving many of the challenges to move BCI into daily usages under realistic conditions.

The recent advances in technology have made some commercially available EEG headsets inexpensive and it is possible to wear a lightweight mobile and wireless EEG headset recording EEG under realistic conditions. Examples of EEG headset that are suitable for daily usage are ThinkGear (NeuroSky, Inc), Enobio (Starlab, Inc), BR8+(Brain Rhythm, Inc.), Emotiv EEG headset (Emotiv systems, Inc.), g.nautilus (G.TEC Medical Engineering GMBH) and so on. Many studies have proved the efficacy of these consumer level EEG headsets in cognitive neuroscience, neuroimaging, and BCI domains [11, 12]. In this study, the Emotiv EPOC is selected for its low price, mobility and high quality of collected data.

Notably the researchers have gained stronger techniques and computing power that basically "fits into a pocket". This has happened for consumer-grade, off-the-shelf devices, such as the smartphones and tablets. The researchers in BCI have got some achievements based on the mobile platform [13,14,15,16].

In this paper we present the design, implementation and evaluation of the dialing system that combines the Emotive and Microsoft Surface Pro3, it is affordable, easy to use and has high mobility. We build an online mobile platform for stimulus delivery, data acquisition and processing with a focus on the dialing system based on p300 speller and also investigated the feasibility of off-the-shelf, consumer-grade equipment in a neuroscience context in lab and metro. The purpose of this paper is to develop a high mobile BCI system and bring BCI technique into our daily life and improve life quality of disable people. The initial results look promising showing that the portable BCI is capable of processing raw neural signals and classifying the P300 with high accuracy.

## II. METHODOLOGY

### *A. Participants*

Twenty healthy subjects (17 males and 3 females, age between 22-25 years) were recruited in this study. Participants were not suffering from any neurological disorders or mental health problems, and were not using any type of medications. This study was fully consistent with the fundamental principles of the Declaration of Helsinki. Each participant read and signed an informed consent before the experiment.

### *B. EEG Equipment*

In this study, a 14-channel Emotiv EEG headset (Emotiv EPOC) was employed to implement the experiment, as shown in left panel of Figure 1, the available channels (AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4) based on the International 10-20 system were depicted in the right panel of Figure 1. The sample rate was 128Hz. In addition because the

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sensor connection quality had great influence on EEG signal and identification results, the TestBench Status Pane was used to monitor the neuroheadset sensors contact quality. The BCI2000 installed in tablet, it can present the visual stimulus and acquire raw signal data from the Emotiv device through a source module contributed by Griffin Milsap [17].

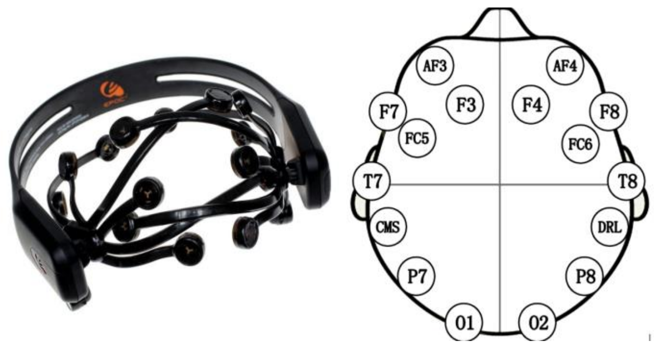


Figure 1. Emotiv Epoc headset (left). Emotiv Epoc headset Electrodes (right). The Emotiv Epoc headset is composed of 14 different electrodes and two references. All the channels named (International 10-20 locations) AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, and AF4 are used in this experiment.

### C. BCI System Architecture

The BCI system addressed in this paper was based on the P300-speller introduced by Farwell and Donchin [18]. The system architecture was shown in Figure 2.

The BCI 2000 was deployed on the Surface Pro 3, which was responsible for the stimulation presentation, EEG processing and targets identification. The visual stimulus was presented on the screen of surface pro 3 (12' LCD monitor). It was consisted of 4×3 matrices of alphanumeric characters and enabled users to spell a cellphone number. The rows and columns of the matrix flickered successively and randomly with a defined duration time between the consecutive flashes (the inter-stimulus interval).

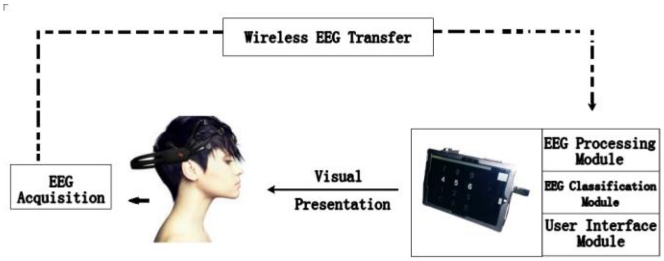


Figure 2. The system architecture of the portable dialing System.

### D. Experiment setup

To evaluate the performance of the portable P300 dialing system based on mobile platform under real conditions, the experiment was completed in lab and metro. The experimental procedure was divided into three periods. During the first period which belonged to machine learning phase and was finished in lab, subjects were asked to sit in front of the screen of surface pro about 0.5 meter. Under the training mode (copy mode), all the characters in the matrix would be identified one time. The user was instructed to focus his/her attention on a particular target and count the intensifications when the columns or the rows that contain the target character (called the target intensification) were flashed. Each row and column in the matrix was randomly intensified for 150 ms and the inter-stimulus interval (ISI) was 200ms. For each character, the 7 columns and rows were repeatly intensified 10 times. There was 1.3 second period between each character of a run. During this procedure the classifier could be trained.

At the second period, the online dialing system based on P300 was tested in lab. Subjects were asked to spell the cellphone number (11 bits) and one confirmation bit (free spell mode). The parameters were same with the training mode. The subjects underwent the experiment with highly concentration and were instructed to avoid any task-irrelevant movements (e.g., contraction of the muscles of the face/head, swallowing, eye blinks and eye movements, motion).During the third period, the same experiments were repeated in metro as in lab. Compared with lab, metro was a more realistic environment with all kinds of unknown factors that could distract the users. The experiment in lab and metro were shown in Figure 3.

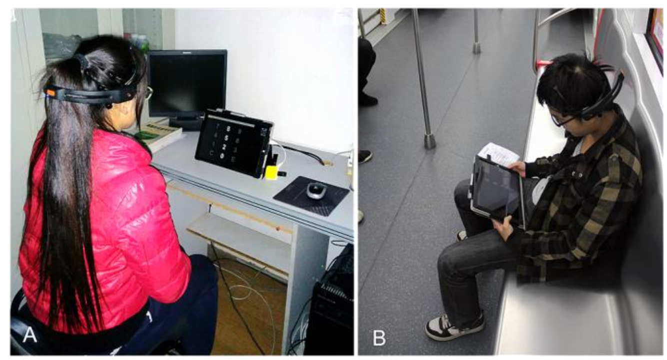


Figure 3. The illustration of experiments in lab and metro. The left panel (A) illustrates the experiment in lab, the right panel (B) illustrates the experiment in metro.

### E. Data Preprocessing and Classification Algorithms

The BCI in this study was based on the P300 speller [8] which enabled users to spell a serial of phone numbers. Because the signal-to-noise ratio (SNR) of EEG signals was very low, and moreover the recorded EEG signals might also contain muscular and ocular artifacts. The data preprocessing was necessary. There were many potential preprocessing methods have been used to handle the EEG problems. In this paper, the EEG data were first filtered by a 2 order Butterworth high pass and low pass filter, the cut off frequencies were set to 0.1 Hz and 45 Hz respectively. Then the average superposition theory was applied to improve the signal-noise rate (SNR), enhancing the P300 evoked potential.

Many classification techniques on data collected using the P300 Speller paradigm had been investigated by Krusienski, D.J., et al [19]. They included the linear methods: Pearson's correlation method (PCM), Fisher's linear discriminant (FLD), Bayesian linear discriminant[20], stepwise linear discriminant analysis (SWLDA) [21] and a linear support vector machine (LSVM), and the nonlinear methods: neural networks and Gaussian kernel support vector machine (GSVM).It has been shown that SWLDA could provide the best performance and implementation characteristics for practical classification of P300 Speller data [19], so it was adopted in this paper.

### F. Performance evaluation

In this paper, classification accuracy and information transfer rate (ITR) were used to evaluate the performance of the portable P300 dialing system based on mobile platform.

The information transfer rate (ITR) is the most commonly applied metric to assess the overall performance of BCIs. It is described as follows:

$$B_t = (\log_2 N + P\log_2 P + (1-P)\log_2 \frac{1-P}{N-1}) \times \frac{60}{T} \quad (1)$$

where $B_t$ is the ITR in bits/min, $P$ is the accuracy of classification, $N$ is the number of different types of mental tasks and $T$ (seconds/symbol) is the time needed to convey each symbol.

Classification accuracy $P$ is calculated in the traditional way and defined as the ratio of the number of correct commands to the total number of commands.

## III. RESULTS

### A. Detection of P300

The portable system recorded responses of the participants to the targets and no targets, as shown in Figure 4. Figure 4 A presented the averaged r-squared (coefficient of determination) values for all participates which indicated the channels response to P300 at different time. It also confirmed the activated area of the brain after a P300 visual stimulation. The typical responses of the participants to the visual stimulation and compared to the no stimuli were presented in Figure 4 B. The figure confirmed the feasibility of the mobile platform to detect P300.

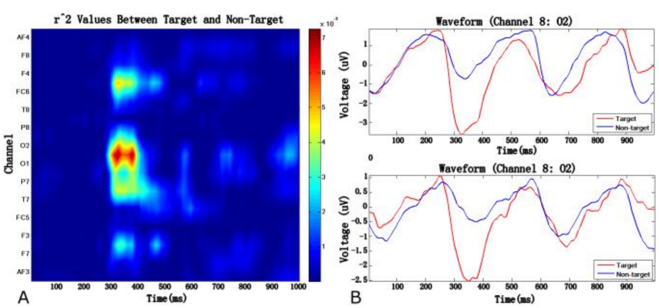


Figure 4. A. The averaged r-squared values plot for all participates. B. The multi-trial averaged typical P300 response. The red line shows the EEG activity elicited by the target stimulus, while the blue line shows the activity for the non-target stimulus.

### B. Online decoding accuracy

The online discrimination accuracy and ITR for all subjects both in office and metro were presented in Table 1. In general the performance of the portable BCI system was not bad, the average accuracy in office reached 88.75±10.57%. However the accuracy decreased to 73.75±16.94% while in metro. Through the ANOVA signal factor analysis (P<0.01), there were significant difference between two conditions and this mean the BCI system was under-performance in metro.

### C. Subject differences

The results also showed significant differences between individual users' performance, the participants S7 had the highest classification accuracy (100%) while S19 had low accuracy (average 54.17%). This mainly because each subject had unique brain and their responses to P300 stimulation were different. As shown in Figure 5, the top row indicated the response to the target and no target stimulation, while the bottom row showed the activated area, it was obviously participants S7 responded strongly to the visual stimulus, in contrast, the amplitude of the signals generated by participants S19 were weak, resulting in a very low performance.

Table 1. The performance of portable dialing system in office and metro.

| Participant | Accuracy (%) | | ITR(Bit/Min) | |
|---|---|---|---|---|
| | Lab | Metro | Office | Metro |
| S1 | 100 | 83.33 | 9.23 | 6.07 |
| S2 | 100 | 100 | 9.23 | 9.23 |
| S3 | 75.00 | 66.67 | 4.92 | 3.90 |
| S4 | 91.67 | 75.00 | 7.42 | 4.92 |
| S5 | 100 | 91.67 | 9.23 | 7.42 |
| S6 | 75.00 | 75.00 | 4.92 | 4.92 |
| S7 | 100 | 100 | 9.23 | 9.23 |
| S8 | 83.33 | 83.33 | 6.07 | 6.07 |
| S9 | 83.33 | 66.67 | 6.07 | 3.90 |
| S10 | 83.33 | 66.67 | 6.07 | 3.90 |
| S11 | 83.33 | 33.33 | 6.07 | 0.93 |
| S12 | 75.00 | 75.00 | 4.92 | 4.92 |
| S13 | 91.67 | 83.33 | 7.42 | 6.07 |
| S14 | 83.33 | 66.67 | 6.07 | 3.90 |
| S15 | 100 | 75.00 | 9.23 | 4.92 |
| S16 | 91.67 | 91.67 | 7.42 | 7.42 |
| S17 | 91.67 | 66.67 | 7.42 | 3.90 |
| S18 | 100 | 58.33 | 9.23 | 2.99 |
| S19 | 66.67 | 41.67 | 3.90 | 1.51 |
| S20 | 100 | 75.00 | 9.23 | 4.92 |
| Average(Mean ±Std) | 88.75±10.57 | 73.75±16.946 | 7.17±1.80 | 5.05±2.17 |

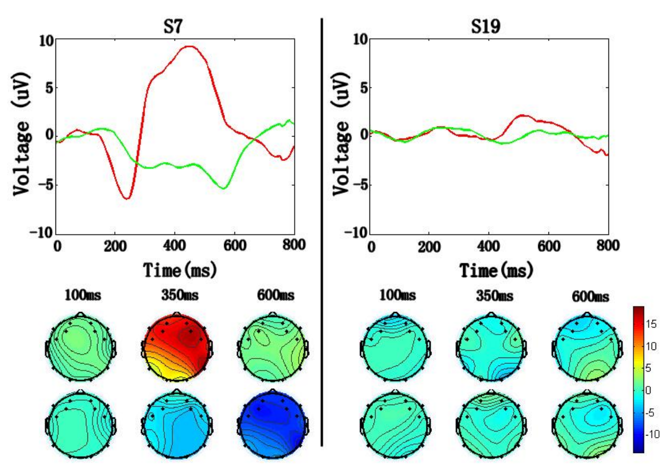


Figure 5. The response of subject S7 and S19 to target and no target stimulation. S7 has strong response while S19 has weak response.

## IV. Discussions and Conclusions

The technologies associated with BCI are developing quickly and the BCI has more and more applications in the past decades. However, most BCI applications are restricted to laboratory's conditions and have a long way to go from the real application. It is mainly because the EEG acquisition system is expensive and need to be operated by experts, also the BCI platform, including stimulus presentation and data processing, is need to run on the computer. In this article, the portable dialing system based on p300 has been undertaken to evaluate the feasibility of Emotiv EPOC as an affordable EEG recording system and the tablet, Microsoft Surface Pro3, as a BCI2000 platform for real-time signal processing. Additionally the performance of the portable BCI system was evaluated in the lab and under realistic conditions.

In terms of the feasibility of the whole mobile platform, including Emotiv headset and tablet, this portable system has evidenced its capability to work as a dialing system based on P300. The performance of the system is comparable to those presented in other studies in which expensive medical EEG recording systems and desktop computer were used. However the performance of portable system decreased as participants switched from lab to metro, a significant drop ($p < 0.01$) in accuracy and ITR was found under realistic conditions.

The reason might be the influence of subway environment that including the lighting, dizzy, attention, and so on. The subjects report the strong light in subway has an influence on their gazing the character on the screen even several subjects feel a litter dizzies during the experiment. Another very important affect may be the public environment that is a little noisy and some onlookers near the participants, which will distract the participants and cannot keep concentrating.

Notably, the phenomenon of "BCI illiteracy" exists in the experiment. Some subjects are not capable to produce a distinguishable response to target stimuli and have low performance. This reflects a potential problem in BCI applications introduced by Brendan and Neuper in their study "could anyone use a BCI?". According to the past studies, about 10-20% of people are not suitable to use a P300-based BCI. So it is necessary for the subject to attend the pretest to identify whether the P300-based BCI is suitable to him. Anywhere there are several ways to overcome this problem.

Other ways to enhance the accuracy including the improving of classification algorithms, employing other easier detectable brain activities, and other neuroimaging methods such as MEG, fMRI. Also the improvement of the stimulation paradigm may help to improve the speed, accuracy and reliability.

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