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Are low cost Brain Computer Interface headsets ready for motor imagery applications?

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ABSTRACT

Low cost electroencephalography (EEG) headset devices for brain data capturing are fast becoming a key instrument on Brain Computer Interface (BCI) applications. In spite of being a controller device initially developed for gaming, the research community has adopted them as a key element to gather EEG data. However, there have been little discussion about their performance when being compared with professional and research EEG headsets.

This paper provides an assessment of one of these devices, the Emotiv EPOC, on a motor imagery problem. As a benchmark, the data and results presented for the Data Set V of the BCI Competition III have been used, which were recorded with a professional Biosemi Active 2 EEG headset. From the perspective of a final working application, it is shown that the performance of this headset is comparable to that found in professional devices when using the same number of sensors and sensor positions for a three status motor imagery cognitive process. This finding implies an increase on the number of EEG headsets the researchers and manufacturers of BCI systems applied to motor imagery problems can integrate and a reduction of their cost.

As part of this paper the Emotiv EPOC recorded raw and pre-processed datasets are published to allow further improvements and comparisons.

1. Introduction

The EEG headsets are the most relevant brain signal capturing devices in the scientific environment, accounting for over 80% of the publications related to BCI systems (AlZu'bi, Al-Zubi, & Al-Nuaimy, 2011). Different manufacturers and headset models used by different researchers, apart from information being recorded from different subjects, have always imposed a challenge when comparing the achievements presented. Moreover, low cost EEG headsets are fast becoming a key instrument in research applications despite of being originally designed for video gaming and entertaining. Therefore, the need of a comparison between the precision and performance of research and low cost headset based BCI systems has become a major area of interest.

The purpose of this paper is to evaluate the accuracy attained by a low cost headset using data recorded by a professional device as a benchmark, both from the perspective of a complete BCI system. Thus, the performance of the low cost Emotiv EPOC headset as an EEG signal acquisition device is compared with the standard BCI Competition III Data Set V benchmark problem.

The BCI Competition contest was organized with the aim of promoting the BCI technologies, providing with common data sets to evaluate the accuracy of different pre-processing and classification algorithms and methodologies. Several calls of this contest were organized where different classic BCI problems were outlined. As part of the BCI Competition III the "Data Set V: Multiclass Problem, Continuous EEG" was provided (Blankertz et al., 2006) . The problem consisted of properly classifying three mental tasks: left hand movement, right hand movement and generation of words beginning with the same random letter. The availability of this standardized dataset in particular has allowed the research community to create a considerable amount of literature after the BCI contest (Aler, Galván, & Valls, 2009; 2010; 2012; Bueno & Bastos-Filho, 2015; Galán, Oliva, & Guardia, 2007; Ghosh, Mazumder, Bhattacharyya, Tibarewala, & Hayashibe, 2015; Lin & Hsieh, 2009; Martinez-Leon, Cano-Izquierdo, & Ibarrola, 2015; Moon, Bawane, & Hazare, 2015; Sun & Zhang, 2006; Sun, Zhang, & Lu, 2008).

Likewise, the demand for easy-to-use, low cost, wireless EEG systems designed for non-research applications such as video games and

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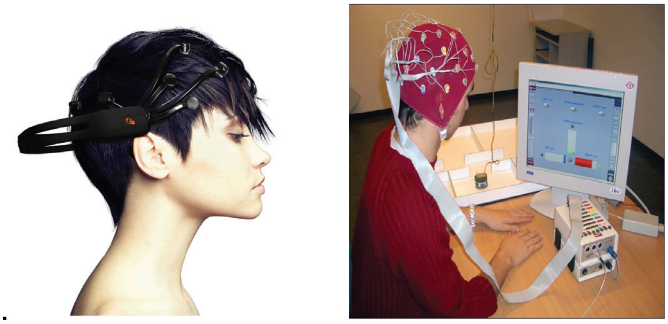
0957-4174/



Emotiv EPOC (Emotiv, 2015) Biosemi Active 1 (Millan & Carmena, 2010)

Fig. 1. Headset physical features comparison (Millan & Carmena, 2010).

entertaining (Van-de Laar, Gurkok, Plass-Oude Bos, Poel, & Nijholt, 2013; Van-Vliet et al., 2012; Vourvopoulos, Liarokapis, & Petridis, 2012), has paved the way for the creation of new neuroscience applications. Brands like (Neurosky, 2015) or (Emotiv, 2015) have created user-friendly headsets aimed at this public, while because of their research use, have released application program interfaces (API) allowing access to the raw brain signals captured. Due to having the highest number of sensors integrated (14) and its usability and setup time, the Emotiv EPOC is an appealing option for researchers as Fig. 1 shows on the left side.

Also, several studies have documented that the Emotiv EPOC headset shows a good performance when detecting mental activity with the aim of identifying several mental actions (Taylor & Schmidt, 2012). Moreover, a number of investigators have reported an increasing number of applications in different BCI research areas. For instance, Khushaba et al. (2012); 2013) use it to study the mental tasks associated to the choice decision making. In Badcock et al. (2013), the Emotiv EPOC headset is evaluated for the auditory event-related potential capturing, leading to the positive outcome of being considered a valid alternative to undertake the issue. Analogous outcome is presented by Clemente, Rodriguez, Rey, and Alcañiz (2014), where the brain activations elicited by the presence in a virtual environment are analyzed. Other researchers have also included it in the implementation of an interface with assistive technologies (Lievesley, Wozencroft, & Ewins, 2011), in the movement of orthotics for stroke patients (Fok et al., 2011), for robot control (Esfahani & Sundararajan, 2011), or in vehicle (Cernea et al., 2011) or tractor driving (Gómez-Gil, San-José-González, Nicolás-Alonso, & Alonso-García, 2011), where the accuracy of the system is compared with different guiding methods such as GPS or manual.

Debener, Minow, Emkes, Gandras, and Vos (2012) replace the Emotiv EPOC sensors by sintered Ag/Cl electrodes and a cap is also integrated to redistribute their position. The system is then used to capture EEG data from static users in an isolated environment as well as users in an external one. It is shown that a mobile BCI system based on a low-cost EEG headset is possible. A similar hybrid system is used in Stopczynski et al. (2013), where an acquisition and analysis low cost system allowing quality-enough data to undertake multiple classical neuroscience applications including Brain Computer Interfaces, analysis of high-level brain activity and neurofeedback, is proposed. The same system has been used once again in De-Vos, Gandras, and Debener (2013) and the possibility of taking quality enough data from walking subjects is demonstrated.

Duvinage et al. (2013) carried out a comparison between a medical system and one using the Emotiv EPOC headset. The outcome of the previous work shows a lower accuracy of the Emotiv EPOC when compared with a medical system in classification problems, although Emotiv EPOC it is still considered by the authors a valid alternative when restricted to non-critical applications. Bobrov, Frolov, Cantor, Fedulova, and Zhavoronkov (2011) analyzed mental tasks related of image classification: think about a house, a face and relax. The results attained by both an Emotiv EPOC and an ActiCap are compared as alternatives for data capture.

More recent literature highlights the importance of BCI systems based on the Emotiv EPOC headset for the research community in different applications. Kumari and Vaish (2015) present a work where the headset has been used to build an authentication system based on visual stimuli while Dkhil, Neji, Wali, and Alimi (2015) build a system to detect drowsiness in drivers traveling long distances. Also, with a more medical focus, McMahan, Parberry, and Parsons (2015) integrate this same EEG headset to assess the cognitive processes happening in the brain of people playing video games, finding power changes on the beta and gamma bands.

From the different works presented above, it can be stated an increasing interest of using low cost EEG systems, like the Emotiv EPOC. For this reason, it is of an interest to apply these low cost systems to end to end problems and compare them with standard benchmarks. Several researchers demonstrate that the quality of the data recorded by using Emotiv EPOC cannot compete with the quality of the data recorded using professional devices, moreover when it comes to evaluate raw signal parameters like signal to noise ratio of the artifacts. However, Emotiv appears to be a viable alternative when the focus changes to application development or to provide with useful data to test classification algorithms.

In AlZu'bi et al. (2011) the use of the Emotiv headset is applied to the Dataset I of the BCI Competition IV (Tangermann et al., 2012). In this study, similar accuracy levels are achieved applying the same methods in both the contest data and the data set recorded from different users wearing an Emotiv headset.

In these scenarios, factors like the signal preprocessing or the classification methodology can reduce the relevance of the quality of the raw data, as they have an important effect in the accuracy of the system.

The Emotiv EPOC datasets used for the BCI system comparison presented in this paper have been recorded based on the multiclass motor imagery paradigm using continuous EEG. Obviously, the signals are recorded from different subjects to those of the BCI Competition Data Set V and it can be seen that the distribution of the sensors is not the same as the one on the BCI Competition either. These restrictions imply that the comparison between both datasets needs to be done at the application level, for instance comparing the accuracy of both systems when completing the same defined task: predict a mental action.

The BCI system built in this research is based on a S-dFasArt classification methodology (Cano-Izquierdo, Ibarrola, & Almonacid, 2012). The ARTMAP architecture model facilitates the interpretability of the data, adjusting the size of the categories in an adaptive way according to the learning data. This feature makes this technology very powerful in scenarios with very noisy signals. On the other hand, the calculations required to produce a prediction are heavy. Approaches like the one presented in Úbeda, Iáñez, Azorín, Sabater, and Fernández (2013) can present faster responses, although the classification success rate achieved is lower. Therefore, the authors have already undertaken the task of reducing the calculations by reducing the size of the input data as shown in Martinez-Leon et al. (2015).

Section 2 includes a description of the datasets used. For the Emotiv data, we have tried to create the same conditions and use the same methods as those used to create the Data Set V. Likewise, a description of the pre-processing stage and the Neuro-Fuzzy classification method used in both data sets is also provided in Section 3. Section 4 details the results of the calculations made to the different dataset configurations, which are discussed on Section 5. Finally, Section 6 summarizes the main conclusions obtained. The recorded datasets containing the raw signals captured with Emotiv EPOC and pre-processed datasets calculated to perform the calculations presented on this paper are made public for other researchers as part