Implementation of an Inexpensive EEG Headset for the Pattern Recognition Purpose

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Abstract – There are many types of bio-signals with various control application prospects. In this work possible control application domain of electroencephalographic signal obtained from an easily available, inexpensive EEG headset – Emotiv EPOC was presented. This work also involved application of an embedded system platform. That solution caused limits in choosing an appropriate signal processing method, as embedded platforms characterise with a little efficiency and low computing power. Potential implementation of the embedded platform enables to extend the possible future application of the proposed BCI. It also gives more flexibility, as the platform is able to simulate various environments. In this work traditional, statistical methods were neither used nor described.

Keywords – EEG signals; Brain-Computer Interface; signal processing; embedded platforms; Emotiv EPOC headset; bio-informatics; robotics; control

I. INTRODUCTION

Application of various bio-signals – in particular EEG – as a source of information used for control of external environments became recently a growing concern in the scientific world. Implementation of EEG signals in Brain-Computer Interfaces (BCI) as an implement enabled fast and direct communication between the human brain and an external device.

The majority of the proposed BCI systems require expensive equipment with high computing power as it uses complex signal processing methods. It is because the analysis of EEG signals is very complex due to the presence of various internal and external artifacts. The signals are also sensitive to disturbances and non-stochastic, what makes the analysis a very complex task.

In this paper a novel EEG signal processing method was presented. The novelty of the proposed solution relies on application of the basic mathematical operations instead of implementation of complex signal processing methods. Experiments for the study purposes were conducted in conditions similar to real-life environment.

II. RESEARCH METHODOLOGY

Currently available on the market, BCI solutions require complex signal processing methodology, which results in the need of an expensive equipment with high computing power. The proposed method was, as mentioned above, based on basic mathematical operations. This has cause that it did not require implementation of measurement equipment with high computing capability.

A. Conducted Experiments

Experiments were conducted in similar to real-life conditions in order to enable possible use of the solution in products such as wheel chair on crowded streets. The subjects, which took part in the study, had to imagine appropriate hand movement, according to the message appearing on screen. The screen presented in the Fig. 1 acted as a visual stimulus for the research participants. Instructions were displayed on it.

Figure 1. Sample screen with instructions for participants.
In the Fig. 2 an anonymous subject during the carried out experiment was presented.

![Figure 2. Subject with Emotiv EPOC headset during experiment.](image)

The data was obtained during recording from the two electrodes. The electrodes were placed on positions – F3 and F4, according to the 10-20 EEG electrodes placement system. Imaginary right-hand movements were recorded from the F3-electrode, while F4-electrode provided signal occurring during imaginary left-hand movements (Fig. 3).

![Figure 3. Placement of used electrodes – F3 and F4.](image)

**B. Implementation**

During the study, inexpensive, easily available on market EEG headset Emotiv EPOC was applied. The headset is not a medical equipment and therefore does not register data with medical precision. The purpose of this work was to present possible implementation of this sort of hardware and to build cheap, but efficient BCI.

The Emotiv EPOC headset consists of 16 electrodes, but only 14 are placed on scalp. The sampling rate of the device is 128 [Hz] and the bandwidth is between 0.2 and 45 [Hz] [1], [2]. Emotiv headset can also be successfully used for user emotions recognition, enabling a possible wider use as opposed to a traditional clinical EEG-equipment [3]. The device has three types of controls – EEG, EMG and Gyroscope. The device has fewer scalp contacts than a typical, expensive, professional device. It also has potentially less accuracy than a typical EEG [4], [5].

![Figure 4. Emotiv EPOC headset [1].](image)

**C. Mathematical Interpretation**

The proposed solution can be presented with the implementation of only the basic mathematical operations, such as addition, subtraction, multiplication and division:

\[
\epsilon = \frac{(1 - \alpha)}{N} \sum_{k=0}^{N-1} [\tilde{s}_i(kT_s) - \tilde{p}_i(kT_s)]^2 + \\
+ \frac{\alpha}{M} \sum_{l=0}^{M-1} \left[\tilde{S}_j(lf_s) - \tilde{P}_j(lf_s)\right]^2
\]

where \( t = kT_s \) is the discrete time \( (k = 0, 1, ..., N-1) \), \( \tilde{s}_i(kT_s) \) and \( \tilde{p}_i(kT_s) \), \( i = 1, ..., r \), are the discrete time representations of the \( i \)th signal and its pattern (or model), respectively, sampled at the frequency \( F_s = \frac{1}{T_s} \), where \( T_s \) is the sampling interval, \( \tilde{S}_j(lf_s) \) and \( \tilde{P}_j(lf_s) \) are the single-sided amplitude spectra of \( \tilde{s}_i(kT_s) \) and \( \tilde{p}_i(kT_s) \), respectively, with \( f_s \) being the frequency step-related to (but not necessarily equal) to \( F_s \). Normalisation guarantees that \( (\tilde{s}_i, \tilde{p}_i, \tilde{S}_j, \tilde{P}_j) \in [0,1] \) and thus the \( \epsilon \) values always belong to \([0,1]\).

There are two components of signal to analyse. The \( \alpha \)-weighted difference between the pattern and the signal
is set up for both domains – the time domain and the frequency domain. In case the signal is very noisy, then – as a result – its time-domain representation may not be very useful for the research purposes. In this case the $\alpha$ coefficient should be set to the value '1' or very close to '1', so that only the frequency domain component would be taken into account. Typically – as the 'best' solution – the value of the $\alpha$ coefficient should be set to 0.5, which means that both components are equally important. The novelty of the diagnostic (or pattern recognition) approach adopted here is an application of a threshold imposed on $\epsilon$, which enable to make decisions on the quality of pattern recognition.

III. SAMPLE RESULTS

As a result of the study analysis of signals recorded in noisy environment was presented. Figure 5 present signals gathered from Subject 3 and Subject 7. Signals were recorded in noisy environment during imaginary-right hand movement. As a result – the signals matched, despite being recorded from different subjects. Both signals were registered during the same task. No filtering was done, the compared signals were raw and unprocessed.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{image1.png}
\caption{Imaginary right-hand movement – 'F3'-electrode – noisy environment – raw signals.}
\end{figure}

Figure 6 presents the same signals in a scaled view. This means, that the values were multiplied by ratio, so the values of the signals were presented in a normalised – [0-1] form.

It is possible to notice 'peaks' present in signal, what may be considered as potential artifacts. However the proposed method contains features of mean-square method. This means that this method has attributes of averaging the values and as a result – the eventual 'peaks' occurring in signals will be eliminated.

IV. CONCLUSIONS

In this study traditional complex statistical signal processing methods were not involved. The novelty of the proposed solution relies on application of the basic mathematical operations. The proposed method is simple, novel and efficient. No filtering was done as it did not improve the results. It is also important to mention, that the Emotiv EPOC provides wireless USB connector and has relatively good battery life – up to 12 hours work [6]. The signals recorded with Emotiv EPOC headset are quite noisy [7].

All the numeric procedures of this work were conducted in MATLAB. Adopted tools for signal processing could be more sophisticated, although it might led to prohibitive computational burdens, in particular in the embedded system environment selected owing to the low-cost implementation prerequisite. Also the implementation of Emotiv EPOC headset had some disadvantages, as the device was not used for clinical applications and therefore the accuracy of the registered signal was not very high, however the conducted initial tests proved efficiency and suitability of the implementation of the proposed solution in real-life environments.

A. Contribution of the Proposed Method

As it was mentioned above, equipment used for the research purposes was not designed for clinical use. It is inexpensive and easy to use (also for inexperienced potential user) [1], [8]. The proposed device became very popular recently among other BCI researchers due to its intuitive user interface and price [8], [9].

Other BCI solutions (eg. Khushaba – [11], Volosyak – [12] or Cholula – [15]) are based on analysis of various brain-signals, such as $\alpha$, $\beta$ or $\gamma$, unlike the proposed by the authors of the hereof paper method, where only the $\mu$ waves are being processed. The previously method also required high computing power, what makes it impossible to implement in traditional embedded platforms.

The novelty of the described method relies also on
its simplicity and lack of traditional statistic methods, applied in other BCI systems (e.g. [11], [12], [15]). For the research purposes only two electrodes were taken into consideration, and as a result only two channels have been used – F3 and F4 [12].

The proposed method’s efficiency is 91.7% in case signal was gathered in quiet environment, recorded during left hand movement from the electrode placed on ‘F4’ position, which was surprisingly high. However, in case the same signals, from the same electrode were gathered in different conditions – noisy environment – the efficiency dropped to 86.7%. For the signals (both – noisy and quiet environment) obtained during right-hand movement and recorded from the ‘F3’ electrode – the efficiency was the same – 86.7%.

Traditional methods – SSVEP (Steady-State Visual Evoked Potential) or P300 Paradigm oscillate between 69.2% and 100% and require higher computing power [12], [14], [15]. SSVEP BCI solution’s overall pattern-recognition efficiency (presented in: [14]) was 84%, which is much lower than the effectiveness of the solution proposed by the authors of this paper. Both SSVEP- and P300-based BCIs require implementation of complex signal processing method and therefore would not be suitable for the method used by authors of this publication [14], [15].

To sum it all up – the novelty of the proposed solution (despite its simplicity and limitations) relies on repudiation of the traditional signal processing methods based on complex statistics. The use of basic mathematical operations enables potential implementation of the methods in embedded systems with small computer power. The method can be also easily transferred into any programming language – including C or Assembler.

During very thorough literature studies similar method have not been found.

B. Limitations of the Proposed Method

All mentioned above numeric procedures were carried out in MATLAB. Implementation of the embedded platform has caused significant limitations in choosing appropriate signal processing method. It also precludes application of advanced neural networks, as the traditional embedded platform’s microcontroller would not be able to proceed the computing.

The conducted research was carried out on a small (for statistic criteria) group of subjects and therefore the obtained results could be unreliable, however it could be consider as a preliminary study (similar to : [13], [14]).

Analysis of efficiency of the proposed solution for the particular candidates has not been done at this stage.

As mentioned above – sophisticated signal processing methods cannot be used as it may cause prohibitive computational burdens. Also the device itself (Emotiv EPOC headset) had some disadvantages, as it was not designed for clinical usage. The obtained signals did not contain full information unlike it is in case the signals are recorded with typical electroencephalograph. The recorded EEG signals had also a very low accuracy.

At this stage the systems was based on communication between PC and TS-7260 (embedded platform) and between Matlab and PC. The main aim of this work is to build a fully working, standalone BCI system with no need of using Matlab or PC. The scheme of the BCI system described in this paper was presented in Fig. 7.

Figure 7. Scheme of the communication between the BCI components.

V. FUTURE WORK

The further study will focus on improvement of the signal-processing method and application of other bio-signals – in order to extend the possible applicability and ameliorate its effectiveness. It will also involve improvement of the proposed algorithm in order to improve the pattern recognition efficiency. There are also plans for conduct more experiments with the implementation of other inexpensive, easily available on market headsets in order to obtain more data and to make the proposed method more reliable.
As mentioned in the previous Sub-section, all numeric procedures were carried out in Matlab. The further research plans involve building a standalone system, where not only EEG signals will be used, but also other bio-signals such as speech, EMG and EOG.

Research will also be conducted on wider group of subjects in order to make the obtained results more reliable.

REFERENCES