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A New Visual Feed-back Modality for the Reduction of Artifacts in mu-Rhythm Based Brain-Computer Interfaces

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Abstract – **A common problem in EEG recording sessions is that results can be heavily contaminated by artifacts. One of the main reasons is that eyes movements generate a noise signal that superimpose to the data.**

In some BCI protocols the user has generally to control the movement of a cursor on a PC screen by self-regulating his/her mu-rhythm. In general this requires the user to move the eyes to follow the same cursor, thus intrinsically generating a huge amount of noise. To overcome this problem a new feedback modality has been developed, which is able to dramatically reduce the artifacts as it does not require subjects to move their eyes.

Index Term – **Brain Computer Interface, Artifacts, Feedback, mu-rhythm.**

I. Introduction

Eye movements represent a noise source that contaminates EEG data. In many BCI experiments, in which keeping the signal to noise ratio as high as possible assumes a fundamental relevance, this fact can dramatically reduce the performances of the whole system.

Some studies tend to overcome this problem especially playing on special spatial filtering techniques [1]-[3]. Nevertheless, even if successfully applied, they require additional processing capabilities that could not be available on all the platforms, such as wearable systems [4]. For this reason, implementing hardware solutions have been recently proposed [5].

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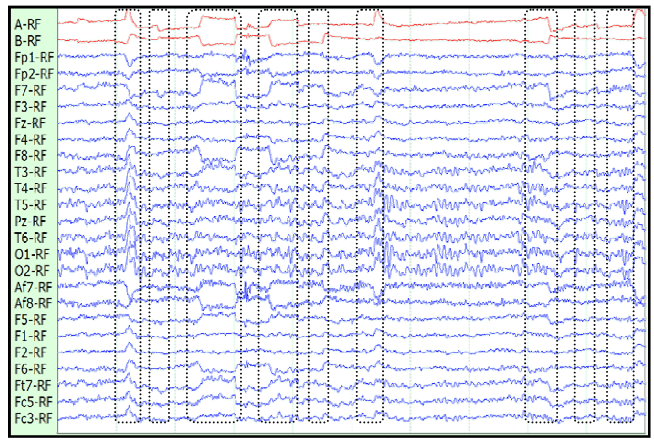

Figure 1 – Ten seconds of EEG recording contaminated by ocular artifacts. Red traces indicate EOG activity while EEG traces are colored in blue. It is clearly visible that artifacts on EEG traces (dotted rectangles) occur during eye movements.

However, there are some BCI protocols, such as those in which a cursor movement on a PC screen is controlled by the self-regulation of the mu-rhythm [6], that could benefit from a simple redesign of the protocol, without requiring additional hardware of software processing. In these cases, in fact, electro-oculographic (EOG) artifacts are mainly due to the way the visual feed-back is provided to the users: these lasts have to control and follow the movement of a cursor on a PC screen with the eyes, a fact that introduces a lot of EOG artifacts on the EEG recordings. This is visible in Fig. 1, where EOG (red lines) and EEG traces (blue lines) are reported: blinks and saccadic movements can be identified in many EEG traces. This fact lowers the SNR of the EEG signals so that in general the performances of the BCI systems degrade.

For this kind of protocols, however, it should be more convenient to provide a different feedback modality: instead of moving the cursor on a screen, that causes a large number of saccadic movements, the background of the screen is moved while the fixation point remains in the same position, such as fixing a central point on the screen with a moving background scene, thus avoiding eye movements, rather than forcing the subject's eye to follow a moving pointer on a fixed scene, as usually done. This simple method, even if unable to avoid eye blinks, reduces the artifacts by about 75%.

In Fig. 2 a comparative description among the two methods is reported.

On the top row the classical feedback modality is illustrated: the cursor, that is the white circle in the figures, moves in the direction of one among the 8 different rectangular targets. The user then, controlling the movement of the cursor by means of the modulation of his μ-rhythm, moves the eyes to follow it.

On the bottom row, as in the proposed modality, the white circle remains fixed in the central position while the random dotted background and the 8 targets are moved in the direction of the white circle, as if they were attracted by it. A noisy background provides a strong feedback to the user, so that it perceives the movement of the target and its direction with the peripheral vision without the need of actually moving the eyes.

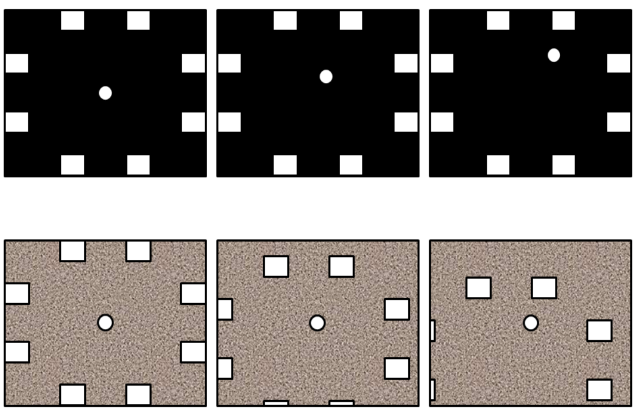

Figure 2 – The two different feedback modalities provided. On the top row the classical one is shown: the circular cursor has to reach the white rectangular target. On the bottom row, instead, the rectangular target is "attracted" by the white circle and has to reach it.

Preliminary results on five subjects show that it is possible to reduce ocular artifacts by nearly 4 times adopting the here proposed novel method.

II. MATERIALS AND METHODS

For the implementation of the graphical engine which is able to provide the feedback in this novel modality, the Simple DirectMedia Library (SDL, http://www.libsdl.org) was utilized. It is a cross-platform multimedia library designed to provide low level access to audio, keyboard, mouse, joystick, 3D hardware via OpenGL, and 2D video framebuffer.

For the aim of this paper the chosen platform was a Windows XP based machine even if most Linux distributions, Windows CE, MacOS and many other operating systems are also supported. The cross platform requirement was introduced to make it compatible with the BF++ framework [7], a set of libraries and tools for the development of Brain Computer Interfaces on many different platforms [4].

Microsoft Visual Studio 2005 was adopted as integrated development environment, documentation was realized with Unified Modeling Language (UML), and the implementation plays on the C++ programming language.

The software, with full sources, can be obtained from the project web site (http://www.brainterface.com) and freely used and modified for any non commercial use.

As in some cases the BCI system is built with two PCs, one for the EEG data acquisition and one for providing the visual feedback, a socket library was also integrated in the project to allow the communication among them. A communication protocol was also defined for sending commands from the EEG application to the visual feedback one: in this way, the former can compute the new coordinates and notify them to the latter. More than 80Hz of refresh rate were always achieved with different bitmaps and target positions, a fact that guarantees a smooth and natural movement of the feedback.

A photocell on the top left corner of the visual feedback monitor allows to synchronize the two systems: at special times (e.g. at the beginning of a trial) a white rectangle is drawn below it and the signal from the photocell was amplified and acquired by the EEG system, thus acting as a real-time trigger. This represents a reliable method to obtain a time flag which fixes the exact time of the visual stimulation appearing on the screen, since it is not well defined when a graphical command is processed by the PC video card.

Additionally, this solves two main problems:

1) The first is that sending a drawing command to a video card does not guarantee that it will be processed immediately. Very often, in fact, it is actually processed after a couple of frames, a fact that introduces a systematic delay of tenth of milliseconds;
2) The second problem is that the image on the screen is actually updated at a fixed rate (the monitor refresh rate in the case of CRTs) which is asynchronous with respect to the drawing command. This introduces a jittering of about one frame between the time in which the application has sent the drawing command to the video card and the time in which the next frame is actually drawn. This introduces a variable, uniformly distributed delay that can last up to one refresh period.

Synchronizing the EEG data with the exact time instant in which a frame is drawn solves both the problems.

Finally, a Java application was implemented to generate the script for the experiment. This allows to easily set, with a user friendly graphical interface, the background image, the resolution of the screen, the position and size of the targets, the position and size of the fixation point and some other parameters such as various elements color, the socket connection parameters (e.g. IP client/server addresses), etc. Due to its multiplatform nature, this tool can be also used with virtually any platform supported by Java.

Experimental Setup

EEG activity was recorded with an EBNeuro (Florence, Italy) Mizar EEG system, by means of 61 standard electrodes placed according to the 10/10 International System, with a sampling rate of 256 Hz. Reference electrode was on the FCz position while ground electrode was between Pz and POz. Impedances were kept below 10 KOhm. Two additional electrodes were used to acquire EOG signals (ROC and LOC).

Measure protocol

Five healthy volunteers participated in the study (22-43 years in range). Each of them performed two consecutive sessions, one with the classical protocol and one with the new proposed feedback modality. Subjects were instructed to fix the white circle until the collision with a randomly selected white rectangle in both protocols. In the first case eye movements were necessary to perform it, while in the second case they were not. The novel protocol required a couple of minutes of training while the classical protocol did not. In both cases they felt comfortable with both of them at the beginning of the recordings.

At least 15 minutes of recording were acquired for each session but the exact stop time was decided when the subject felt tired. The duration of the second recording was chosen to be equal to those of the first one.

Each trial consisted in a 1 second period in which the screen was static, 3 seconds during which the feedback was generated (movement of the white circle versus the target or of the target versus the white circle) and another one second of static screen.

The inter-trial interval was randomized between 2 and 4 seconds.

Data Analysis

Data were converted into the NPX File format [9] and reviewed with the NPX Lab tool [10] which is a free tool for EEG and ERP data analysis and review. Artifacts were inserted automatically by generating events with the built in capabilities of the software by setting a threshold value of ±35μV on the Average Reference channel after band-pass filtering [0.5-30 Hz]. To further remove the beginning and end of the artifacts, the generated events were singularly extended by 150 ms on both sides. A qualified technician reviewed the traces and manually edited them whenever the automatic procedures generated false positive or missed some artifacts. The signal portions that were analyzed were those during which a trial was running, so that inter-trial intervals were excluded as they are usually not processed in BCIs experiments. The ratio between the total amount of artifacts and the total duration of the trials was then computed for the two sessions and for all the subjects.

III. Results

Results from the two sessions are reported in Tab. I (classical protocol) and Tab. II (proposed protocol). The five subjects are indicated in the first column, the last row representing mean values. In the five successive columns are reported respectively the number of trials, the sum of the trial durations, the number of detected artifacts, the sum of their duration and their percentage (the ratio between columns 5 and 3). In the case of the classical protocol the mean average artifact/signal durations ratio was 18.7%, while in the case of the proposed feedback modality it was less than 5%. This means that the total amount of artefacts was reduced by a factor of 3.84 thanks to this protocol design.

Tab. I
Classical Protocol

	Trials	Signal [sec]	Artifacts [count]	Artifact [sec]	Artifact [%]
LB	72	378	106	67	17.7
DP	132	693	158	89	12.8
CD	126	656	194	181	27.6
LQ	99	520	147	118	22.7
DW	111	583	126	74	12.7
AVG	**108**	**566**	**146.2**	**105.8**	**18.7**

Tab. II
Proposed Protocol

	Trials	Signal [sec]	Artifacts [count]	Artifact [sec]	Artifact [%]
LB	72	382	20	7	1.8
DP	130	691	52	31	4.5
CD	123	653	76	34	5.2
LQ	99	525	86	50	9.6
DW	111	589	27	19	3.2
AVG	**107**	**568**	**52.2**	**28.2**	**4.86**

Also the mean number of artifacts was accordingly reduced (from 146.2 to 52.2) as well as their total duration (from 105.8 sec to 28.2).

IV. Conclusions

Ocular artifacts, due to eye movements, contaminate EEG data and reduce their signal to noise ratio. Some BCI protocols, however, are designed in such a way that eye movements are necessary to make them work.

However, even if some special algorithms have been developed to reduce this contamination problem, it is possible to redesign the way in which the visual feedback is provided to the users to significantly improve the quality of the EEG recordings, thus avoiding the problem itself.

A C++ program has been developed to implement the proposed solution, under the Windows platform and a Java configuration tool was also implemented. Due to its intrinsic cross-platform nature it can be easily integrated into already existing BCI systems.

The total amount of ocular artifacts in the described two different ways of providing the feedback in mu-rhythm based BCI protocols were compared. According to the classical method, one has to move the eyes to follow the movement of a cursor on a PC screen, while in the proposed one the eyes have to stay fixed. The experimental results conducted on 5 subjects clearly demonstrate that a strong reduction of artifacts can be obtained by adopting the novel feedback modality.

This suggests that the proposed method can be tested on real BCI systems and that a reduction on the number of artifacts and then an increase of the performances of a class of BCI systems can be reasonably expected.

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