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A hybrid platform based on EOG and EEG signals to restore communication for patients afflicted with progressive motor neuron diseases

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Abstract—**An efficient alternative channel for communication without overt speech and hand movements is important to increase the quality of life for patients suffering from Amiotrophic Lateral Sclerosis or other illnesses that prevent correct limb and facial muscular responses. Often, such diseases leave the ocular movements preserved for a relatively long time. The aim of this study is to present a new approach for the hybrid system which is based on the recognition of electrooculogram (EOG) and electroencephalogram (EEG) measurements for efficient communication and control. As a first step we show that the EOG-based side of the system for communication and controls is useful for patients. The EOG side of the system has been equipped with an interface including a speller to notify of messages. A comparison of the performance of the EOG-based system has been made with a BCI system that uses P300 waveforms. As a next step, we plan to integrate EOG and EEG sides. The final goal of the project is to realize a unique noninvasive device able to offer the patient the partial restoration of communication and control abilities with EOG and EEG signals.**

I. INTRODUCTION

Establishing an alternative channel for communication without overt speech and hand movements it is essential to increase the quality of life for patients suffering from Amiotrophic Lateral Sclerosis (ALS) or other progressive illness that afflicts the motor system in humans that prevent accurate and correct limb and facial muscular responses. In this respect, the area of study related to the human computer interaction is very important and hopes to improve the medium term quality of the life of such patients. In fact, often such diseases leaves the ocular movements preserved for a relatively long time and in such condition that the EOG-based system for communication and controls are useful for patients. On the other hand, the progressive nature of the illness that degrades motor-neurons in the end leaves the patients without control of their eye movements. At this point, the only way to restore the communication capabilities is through the Brain Computer Interface (BCI) technology that uses mostly electroencephalographic (EEG) data as a carrier of information between the patient and the environment. Although their measurements are quite expensive, magnetoencephalogram (MEG) can also be used for BCI applications. BCI systems are important for the development of assistive and therapeutic technologies for paralyzed patients.

There are several EOG based human computer interface (HCI) applications for different purposes in the literature. A powered wheelchair controlled with eye movements has been developed for the disabled and elderly people. To control direction and acceleration of a wheelchair combined with EOG and sensor signals have been used [1]. As an eye-based human computer interaction; the wearable EOG goggles [2], using wearable electrooculography for recognition of reading activity [3], the control system based on EOG and voluntary eye blink [4], and to control of the computer functions with eye movements [5] have recently been developed. For controlling movable systems; by using the horizontal and vertical eye movements, two and three blink signals are classified and a movable robot has successfully been controlled. [6]. EOG, EEG and electromyogram (EMG) signals have been classified in real time to control movable robots by using artificial neural system classifiers [7] [8].

A reasonable approach for improving the communication channels between patients and the environment as much as possible is to use all the residual abilities of the patients during the evolution of the illness. In this respect, the generation of a common software interface toward the different applications to be driven by the EOG and/or EEG signals could be a good solution to minimize the discomfort for the patient related to the use of different software and programs during the illness evolution. Therefore, the long term goal of this project is related to the generation of a common software and hardware platform for the communication and controls of a demotic environment by using EOG and EEG signals. In Fig.1 the hybrid system is presented.

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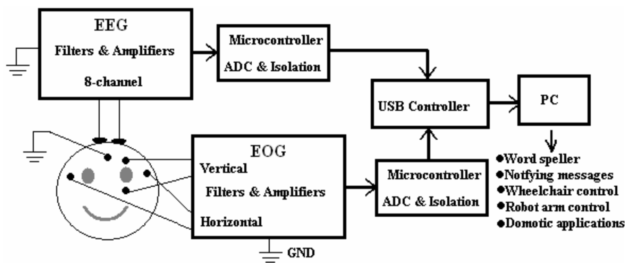


Fig. 1. The hybrid system is that EEG and EOG signals are used together. The combined system hopes to increase communication efficiency for the patients afflicted with the motor system that prevent accurate and correct limb and facial muscular responses.

In this paper we present the EOG side of the new hybrid device, and the comparison of its performances with the EEG based BCI counterpart (8-channel, Guger Tech.) based on the recognition of the P300 waveforms. The aim is to develop a normative database of the speed of use of the two EOG and BCI systems in order to allow a rapid switch between them, (when the performance of the user degrades for some reason) with the use of a particular one. Before generating such an automatic switching algorithm, it is important to fully characterize the average performance in terms of speed of use of the EOG and BCI systems on a population of healthy subjects. The common application developed for both systems is the word speller.

This paper is organized as follows: first, a brief overview of EOG and EEG-based systems for communication and controls will be presented. Then the new EOG based system realized for this project will be illustrated. Successively, the experimental results obtained with such EOG system in a group of healthy volunteers will be described and compared with those obtained by using an EEG based BCI system. Results will be commented on at the light of the generation of a new hybrid device for partially restoring the communication capabilities of patients.

II. MATERIALS AND METHODS

A. A Brief Overview of EOG-based Systems

In eye movements, a potential across the cornea and retina exists. This potential is called the cornea-retinal potential. The cornea is the positive side, and is the source of the electrooculogram (EOG). EOG can be modeled by a dipole [1], and these systems can be used in medical and home care systems, etc. EOG signals show certain patterns for each kind of eye movement (left, right, up, down, and blink). These signal patterns can be recognized, and then the acquired signals can be used for controlling external devices like virtual keyboards, powered wheelchairs, movable arms, and movable robots. The EOG-based virtual keyboard provides a means for paralyzed patients to type letters onto a monitor with eye movements without using a conventional keyboard. The research mainly focused on recognizing eye movements; such as left, right, up and down, and eye blink to select characters from the virtual keyboard onto the screen (i.e. speller).

B. P300-based Brain Computer Interface

Brain Computer Interfaces (BCI) is an area of research that is rapidly growing in the neuroscience and bioengineering fields. One popular approach to the generation of a BCI system consists of recognition by a computer of the patterns of electrical activity on the scalp gathered from a series of electrodes.

EEG based BCI systems can use P300 responses, μ (8-12 Hz) and high β (18-26 Hz) rhythms. BCI systems can provide a communication and control channel, which by-passes conventional neuromuscular pathways involved in speaking or making movements to manipulate objects [9].

In this last decade, high-resolution EEG technologies have been developed to enhance the spatial information content of EEG activity [11] [12]. While this approach is important for the detection of imagined motor activities, the approach here presented is based on the use of the P300 waveform. The P300 is a large, positive potential over midline areas that has been studied extensively within the context of the oddball paradigm. Donchin and colleagues [13] first reported the use of the P300 for BCI communication.

Here, we followed the international approaches for the detection of P300 in the context of BCI. In particular, we have implemented for the speller a matrix of grey symbols on a dark background. Rows and columns of the matrix were randomly intensified. A P300 was produced when the attended row or column flashed. The attended symbol was selected by averaging responses for rows and columns. Accurate performance was obtained in users with and without disabilities. Sellers and Donchin [14] showed that both users without motor impairments and users with ALS were able to use the P300-based, single-stimulus system using either auditory or visual presentations.

C. The New EOG Based HCI Device

In this subsection, the EOG side of the hybrid measurement system design is proposed. The design detail of this system has been presented in [15]. Eye movements are measured with five passive electrodes (Vertical+, Vertical- , Horizontal+, Horizontal- and Ground) usually employed for the EMG or EEG acquisition.

The system is microcontroller based and battery powered. After filtering and the amplification stages, the EOG signals are digitized (10 bit) and then transferred to the PC. By using differentiating approach, dc level and power line noise are removed. For optimization signal visualization, vertical amplifier gain fixed to 74.5 dB and horizontal gain to 77.6 dB. The total gain is provided with cascaded 3 stages. To reject high frequency noise, a low pass filter (LPF, fc=16 KHz) is used. In input stage LT1167 instrumentation amplifier (IA) has been used. Fixing the amplifier gain 16 prevents amplifier saturation due to dc level. This IA has high common mode rejection ratio (CMRR, 120 dB) and input impedance (>1 TΩ). In other stages LMC6001 electrometer amplifier has been used. Having removed the dc level, the signal is applied to 5th order Bessel LPF (with MAX281) and then it is applied to the amplifier with the gain 101. The cut-off frequency of the LPF is fixed to 31 Hz and at the output it is possible to pass 0.15-31 Hz frequency band. To provide digitization to the analog signal and to transfer the PC µC (PIC12F675) has been used. µC output data is isolated with opto-couplers (PC817). Isolated data is applied to the PC via a serial communication port. Sampling rate of the system is 176 Hz. After digitizing, horizontal and vertical EOG signals are then transferred to the PC serial port. Microcode Studio program is used to write embedded code, Winpic800 is used to program the microcontroller (µC).

Because EOG signals can be easily discriminated, the nearest neighborhood (NN) algorithm has been used for classification. The time cost of this algorithm is less than other complex classification algorithms. The Euclidean distances are used for calculation of metric:

$$L(x,y) = \sqrt{\sum_{i=1}^{d}(x_i - y_i)^2} \quad (1)$$

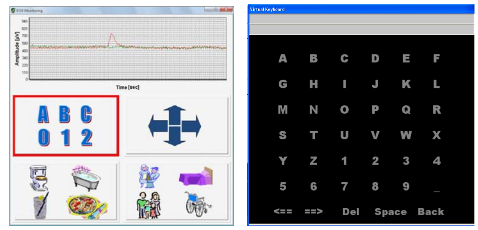
As to the classification, 5 classes (each having 20 members) are used. After detection of the eye movement 75 samples of the members are used for calculation of the distances.

When the EOG measurement starts, the horizontal and vertical EOG signals appear on the user-friendly interface (Fig. 2). With eye movements, the virtual keyboard, needs and motion control sub-menus can be selected. For the selection, left-right and up-down eye movements are evaluated as binary approach. Each cursor movement is performed step by step. If the cursor is in place (on sub-menus or on the letter on the virtual keyboard) one blink is enough for selection. Continuing eye blinks do not cause selection. If the selection is wrong, the subject/patient can return to the main menu or correct misspellings using the "Arrow" "Del" "Space" and "Back" buttons on the virtual keyboard.

III. RESULTS AND DISCUSSION

The overall CMRR of the system is 88 dB, input-referred noise is 0.6 µV (p-p), and sampling rate is 176 Hz. 5 Ag/AgCl electrodes are used (two for each channels and one is for ground). In order to remove the DC level and 50 Hz power line noise, the differentiate approach is used. This approach is much more successful than filtering based classical methods. Data transfer rate is enough for the sampling rate (176 Hz), which is sufficient for the processing of the EOG signals.

The experimental design adopted for the generation of the word "water" was essentially the same of that employed in the case of the BCI system based on the recognition of the P300 waveform. A group of 10 healthy subjects were asked to generate with the eye movements the word "water" by selecting the single letters on the virtual keyboard designed. All the subjects were novel to the use of the BCI operation. A EEG cap was used that employed 8 electrodes placed according to the position F3, F4, C3, C4, Cz, P3, P4, and Pz of the standard 10-20 international system. Subjects were



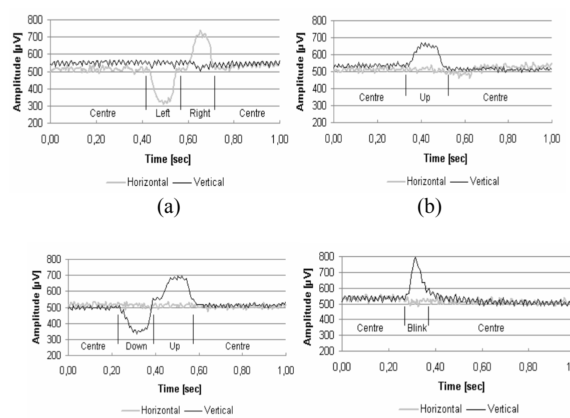
(a) (b)

Fig. 2. User interface: a) Main menu for EOG side. At the top, the real-time EOG signals can be observed. Virtual keyboard and other needs can be selected. b) Word speller screen.

first familiarized with the system and then the purpose of the recordings was explained. The P300-based BCI speller based on the detection of P300 waveforms from the array of 8 electrodes returned in 21 seconds (105 seconds for 5 letters) for the selection of the word "water" in the experimental group employed. In addition, the accuracy of the letter selection as average was of 80 % in the same group, with a standard deviation of 14%. Controls were then able to master the P300 BCI system after a session of 30 minutes at the reported level of accuracy.

The group of 20 subjects that selected the word "water" with the EOG-based device employed an average time of 24.7 seconds, with 3.2 seconds as a standard deviation. In addition the accuracy percentage in this group was 95%. Also in this case the subjects were able to master the device after a session of 5 minutes. As seen from the recordings in Fig. 3, after considering noise reduction measures in designing of the biopotential data acquisition system, the new system can record EOG signals, successfully. The EOG measurement system, as a HCI, allows people to communicate with their environment, only by using eye movements, successfully and economically (180 USD).

From a technical point of view, the highlights of the



(a) (b)

(c) (d)

Fig. 3. The EOG recordings: a) Horizontal (Centre-right-left). b) Vertical (Centre-up). c) Vertical (Centre-down-up). d) Eye blink. Without any additional analysis of the signals such as; averaging, independent component analysis, etc they are distinguishable from each other.

EOG side of the presented system are: a) Horizontal and vertical EOG signals are measured successfully. CMRR is 88 dB, sampling rate is 176 Hz, and electronic noise is 0.6

μV (p-p). According to the specifications, the present system can measure the EOG signals properly; b) The EOG signals, for different eye movements, are classified in real time with a performance of 95%. The NN algorithm (with Euclidean distance) is used. The signals do not need complex and time costly classification algorithms; c) The realized virtual keyboard allows the user to write messages and to communicate other needs. With this system a five-letter word can be written by the subject in 25 seconds and a message such as "clean up" could be performed in 3 seconds; d) The different devices employed in the system, using the EOG and EEG waveforms, reported an average speed of 24.7 seconds for the EOG system and an average speed of 105 seconds for the EEG system for the selection of a word of five letters. It could be stated that the generation of a hybrid device that will use EOG and EEG waveforms for the control of the external environment can be more efficient for communication. This approach is that in the intention of the authors could be generated within the next year of common research.

The EEG-based BCI systems can represent the only technology for severely paralyzed patients to increase or maintain their communication and control options. The choice of the P300 as a paradigm for the EEG-based BCI systems was due to the fact that such waveform occurs spontaneously in about 90% of the subjects without need of particular training and this could be very useful for increasing the chance of success of patients. As a contribution in this area of research, in this study, we present a HCI device that is able to recognize the subject's eye movements by using the collection of the electrical activity generated by the eye movements. This device allows the patients to generate decisions on a screen by means of a simple eye movement signals. These signals can be measured with EMG/EEG electrodes, without the need of sophisticated infra-red cameras. Then, patients are able to select letters on the screen or even communicate basic needs (food drinks, etc.) to the caregiver with a simple movement of their eyes.

IV. CONCLUSION

In this paper we proposed a new hybrid system to use the EOG and EEG signals for the realization of an efficient HCI device able to restore some communication abilities to patients.

The EOG-based side of the system seems more accurate when compared to the EEG-based one. It must be noted that the solution for the EOG system is extremely cheap when compared to the EEG solution (one order of magnitude) and then can be used as a first step for the hybrid device for all the final users. The general idea of an hybrid device is to familiarize the patient with an unique interface while he/she could switch with the bioelectric signal that is more useful for him/her in that particular moment in time for the communication or for the control of the external devices. In this respect there will be the possibility to change the control signals without the need to learn the user interfaces again, which usually happens today with the use of other interfaces.

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