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Hybrid Human-Machine Interface to Mouse Control for Severely Disabled People

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Abstract*— This paper describes a hybrid human-machine interface, based on electro-oculogram (EOG) and electromyogram (EMG), which allows the mouse control of a personal computer using eye movement and the voluntary contraction of any facial muscle. The bioelectrical signals are sensed through adhesives electrodes, and acquired by a custom designed portable and wireless system. The mouse can be moved in any direction, vertical, horizontal and diagonal, by two EOG channels and the EMG signal is used to perform the mouse click action. Blinks are avoided by a decision algorithm and the natural reading of the screen is possible with a specially designed software. A virtual keyboard was used for the experiments with healthy people and with a severely disabled patient. The results demonstrate an intuitive and accessible control, evaluated in terms of performance, time for task execution and user´s acceptance. Besides, a quantitative index to estimate the training impact was computed with good results.

***Index Terms*— assistive devices, human-computer interface, electro-oculogram, electromyographic signal.**

I. INTRODUCTION

Severe motor disabilities are the major cause of limitations in Daily Life Activities (DLA), and can lead to a significant loss of autonomy and communication. A variety of causes such as neurodegenerative diseases, spinal cord injuries (SCI) and transit accidents, leave sequels sometimes extremes, like paraplegia. Assistive technologies can bring a solution to improving their quality of life by providing an adequate Human-Machine Interface (HMI) to use personal computers (PC). The functional capabilities of the patient will determine the signals or commands to control the PC, for example, through the tongue or head movements [1]-[2]. However, at the worst situations, users with SCI may not be able to turn his head requiring more complex HMI.

HMIs provide people with disabilities an alternative tool for communication and entertainment through biological signals such as the electroencephalogram (EEG), the electro-oculogram (EOG) and the electromyogram (EMG). Brain-Computer Interfaces (BCIs) have increased in the last years due to the development of new and commercial hardware [3]-[4] and more powerful computers, able to perform online analysis. However, the social acceptance of severely disabled people is still far, due to the expensive cost, repeatability of electrode placement, and limited portability, among other problems. EMG and EOG signals emerge as suitable alternatives for HMI due to the low cost, robustness, and more comfortable use. The surface EMG signal is the electrical manifestation of neuromuscular activity, originated from the depolarization and repolarization of the muscle membrane during voluntary contractions, measured noninvasively from the skin by using electrodes and biopotential amplifiers. The EMG signal contains information about muscular force and user intentionality, becoming a reference input signal to myoelectric control systems. In the last years, several HMI's based on the EMG have emerged to control electric wheelchairs [5], prosthesis [6] and virtual reality environments [7]. The popularity of surface EMG stems from its cheapness, simplicity of use and non-invasiveness. In order to control multiple functions, it is necessary to map out the EMG corresponding to different muscles, and so composing a multichannel system [8]. Herein, the EMG is used as an ON-OFF command with a single channel configuration over any facial muscle.

The electric potential across the cornea and retina can be measured via external and periorbital electrodes, to pick up the EOG. This potential (approximately 1 mV) is due to differences in metabolic activity between two points and can be modeled as a dipole with a negative retinal and a corneal positive pole. The axis of this dipole coincides with the anteroposterior visual axis and is perpendicular to the vertical and transverse axes of the eye. An electric field is generated around this axis and the eye movement induces changes of approximately 20 μV per degree of eye movement. Any active or passive eye movement causes a change in the position of the electrical axis, which is captured by the periorbital electrodes. These signals have a frequency range from DC to 50 Hz and their behavior is almost linear for angles of $\pm$ 40 degrees. For greater angles, the linearity conditions deteriorate, especially on the vertical axis, preventing to reach higher values (say, $\pm$ 70 degrees) [9].

EOG signals have been used to control electric wheelchairs [10], visual boards [11], mobile robots [12], PC mouses [13]-[14]-[15], and other devices, allowing autonomy in mobility or communication. However, most of these works employ commercial equipment for the biopotentials acquisition, limiting their use to the academic or research area. In [11] the authors present a system based on a microcontroller, optical isolated, that use a nearest neighborhood algorithm to classify the EOG and control a virtual keyboard, activated by an eye blink. The performance was compared with a BCI, with promising results. Other virtual keyboard systems, such as [16], perform the processing stage in the PC by multiple feature classification methods.

In this work, we propose a hybrid HMI based on EMG and EOG signals to control the mouse, low-cost, wireless, and generic to any PC or other assistive device. The main objective is the design and development of an acquisition system and processing software, allowing the positioning of the mouse pointer and the click action. EOG signals are acquired from the user's face through surface electrodes, amplified and filtered out in a custom design device. The acquisition circuit is composed of three channels; the first one for the EOG acquisition of the vertical eye movement, the second one for acquiring signals from the horizontal eye motion and the last one for EMG pick up (Fig. 2). Thereafter, these three signals are digitized with an analog-digital converter (ADC) and sent wirelessly to the PC in order to provide actions to the mouse pointer (horizontal movement, vertical and diagonal pointer and click). A general scheme of the HMI is shown in Fig. 1.

II. MATERIALS AND METHODS

A. Front-end Amplifiers, Analog Processing and Wireless Transmission

Bioelectric potentials recognize an ionic origin and their efficient measurement requires detection with suitable electrodes, such as those used here to pick up the EOG and the EMG [17], that is, bipolar Ag/AgCl skin pads, type 3 M RedDot. Electronic amplification and filtering were implemented by a custom made front-end signal conditioning circuit with the following characteristics:

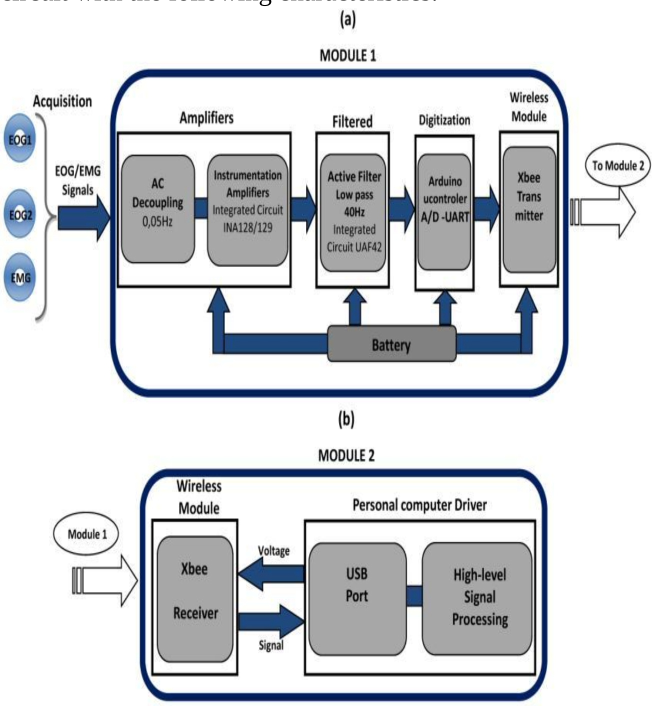

Fig 1 Front-end Amplifiers, Analog Processing and Wireless Transmission. Two diagrams of the electronic modules are shown. (a) Module 1 consists of the amplifier with AC decoupling, the 40Hz low-pass UAF42 filter, the Arduino A/D converter, and the wireless Xbee trans-receiver. (b) Module 2 only communicates Module 1 with a personal computer.

-Amplification stage: INA128, Texas Instruments®;
-Input impedance: 10MΩ;
-Gain: 500V/V for the EOG and 200 V/V for the EMG;
-Common Mode Rejection Ratio (CMRR): 120 dB.

Besides, a high pass filter with cut-off frequency of 0.05Hz performs the DC decoupling, implemented with operational amplifiers and passive components. Active filters include low pass filters with cutoff frequencies of 40Hz for the EOG and EMG signals. Even when it is widely recognized that surface EMG calls for a bandwidth up to 450Hz, frequencies from 0.05Hz to 40Hz have enough information to detect the presence of muscular activity. The filter set at 40 Hz reduces the 50Hz power line interference, so avoiding another filter stage, such as a notch filter. The assembly of these filters is integrated by a UAF42 (Texas Instrument®), single-chip solution, which configuration is low-pass, inverter, and with unity gain.

Post-amplifiers match voltages with the microprocessor. In this stage, gains were set to 10 V/V and a 2V offset was applied to obtain positive values. Besides, an inverter configuration compensates for the inversion of the filtering stage. After conditioning both the EOG and the EMG signals, a microcontroller digitalized two EOG channels and one EMG channel. The device is an Arduino Mini®, which has a 10-bit analog to digital converter and Universal Asynchronous Receiver-Transmitter (UART) communication peripheral, among other technical features. Data were sampled at 100 Hz and grouped in 50-sample packets (or buffers). Each packet is sent at 57,600 bauds by means of a UART wireless unit, actually accomplishing the sending when the control software demands it.

Two Xbee® transreceivers perform the wireless communication at 868 MHz RF with a personal computer. Module 2 takes care of the wireless reception in the PC linked to a USB port. Finally, a software driver was programmed to handle the Arduino digitalization in order to carry out the high-level processing and the virtual interface control.

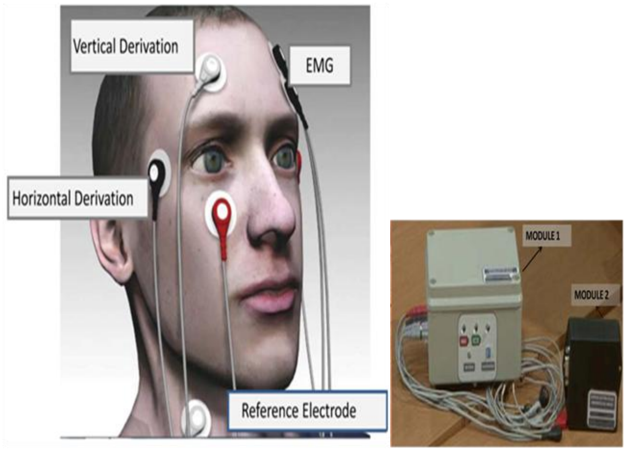

Fig 2: (a) Sensors Position. Bipolar Ag/AgCl (3 M RedDot) electrodes are placed near the eyes and on the forehead for collecting EOG and EMG signals. Pairs of electrodes sense the Vertical EOG derivation, the Horizontal EOG derivation, and the EMG from forehead muscles. A reference electrode is located on the neck. (b) Complete HMI system composed of Modules 1 and 2. See text below.

B. EOG- based movement protocols

Eye movements from EOG signals can be detected by

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selecting out from four basic types of eye movements: saccadic, smooth pursuit, vergence, and vestibulo-ocular [18]. The presence of vergence movements is discarded, because the hypothesis suggests the absence of head movements or the need to maintain binocular vision of a distant object. In addition, artifacts induced by the user's natural blinking during reading on a PC screen are important factors to be avoided, without losing performance and reliability. To accomplish these requirements, two protocols were tested, both based on the tracking of a white object over a black background screen. In the first protocol, namely *Continuous Movement*, a white marker is displaced slowly and continuously, while in the second protocol, called *Extreme Movement*, the marker disappears from an initial position and reappears in another, forcing the user to perform a pseudo-saccadic movement, thus changing abruptly the fixation point (Fig. 3). Both protocols use the same sequence of movements, starting and concluding in the center of the screen:

- Center, up, and back to the center;
- Center, to the right, and back to the center;
- Center, down, and back to the center;
- Center, to the left, and back to the center.

Fig. 4 shows the EOG recorded during both protocols. In the *Continuous Movements* protocol, the EOG shows smooth shifts with amplitudes slightly higher than the baseline, while for *Extreme Movements* instead, the amplitude is higher than the amplitude obtained for the small movements made in the first case. We chose to work with *Extreme Movement* signals to command the mouse pointer, because they are easier to detect due to its large amplitude and short duration.

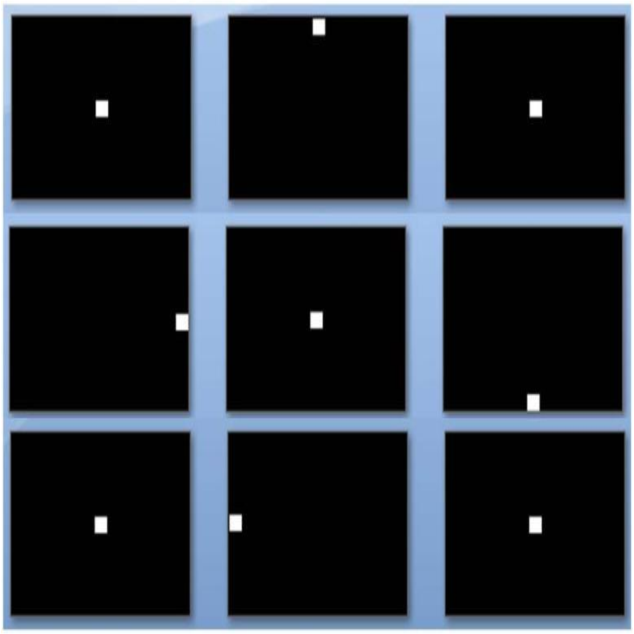

Fig 3: Screen for the experimental protocols. Each panel shows a white object on a black background screen for tracking with the gaze. Two protocols were carried out depending on whether the white object moved slowly (*Continuous Movements*), or suddenly to one end of the screen (*Extreme Movements*). The sequence of pictures corresponds to the sequence of movements.

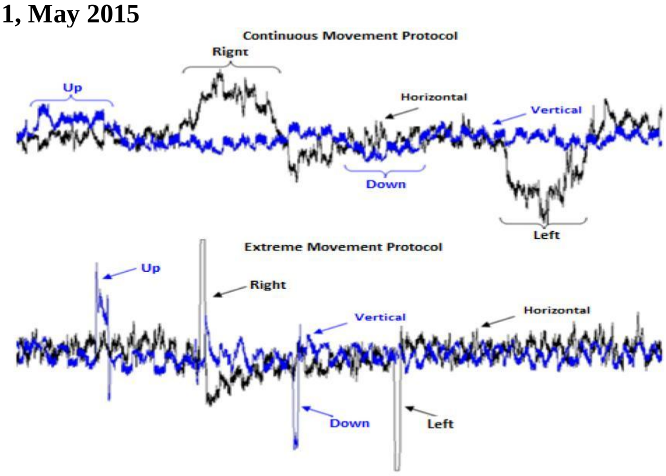

Fig 4: EOG recorded during the experimental protocols. The four signals above show, respectively, the vertical (blue lines) and horizontal (black lines) EOG leads. Upper channels depict slow EOG changes with *Continuous Movements*. Lower traces clearly show abrupt EOG changes for *Extreme Movements*. No doubt, the EOG separates out well the extreme movement.

C. Hybrid-HMI Control Scheme

The user prompts the mouse direction with a gaze *Extreme Movement* to any screen edge, so starting the process. The mouse can be moved upwards, downwards, leftwards, rightwards or diagonally, depending on the EOG combination, and it will do it at constant speed until the user stop the action by a muscular contraction via its EMG. Once the mouse is stopped, a second EMG signal commands the click action. Empirical thresholds were adjusted with five levels of sensitivity. It was determined that when signals in the vertical channel are higher than a reference line, movements are matched to the eyes moving upward, whereas when the signal lies below the line, it corresponds to a downward eye movement. Similar procedure determines the rightward (above the threshold) or leftward (below threshold) directions. Diagonal movements are also permitted, since the EOG channels are combined to determine a single cursor path. Besides, the EMG signal is conditioned by rectification and low pass filtering, and thereafter, a threshold determines a control signal for the mouse click.

The initial calibration of the system allows the choice between five sensitivity levels, because the algorithm must be able to detect the eye direction at the same time that the user focuses his gaze on the PC screen. Environmental conditions, biological variability and other factors can modify the baseline, according to different situations and users. These initial parameters will be used to set the threshold and the velocity of the mouse. The volunteer initializes the trial setting their sensitivity parameters, and the software could set from lower to higher levels of thresholds.

Even when eye blinks have been used as click control signal or other EOG applications [13], blinks events are not fully voluntary and may be interpreted as artifacts. Thus, the click action is assigned to a voluntary contraction in any facial muscle (say, *frontalis*, *masseter*, *zygomatic*). The processed EMG may cause interference with the vertical EOG channel due to sensor proximities. A possible solution

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relies on discriminating the interference by software, giving higher priority to the EMG signal, as depicted in Fig. 5 and 6.That is, if the presence of EMG activity over the *frontalis* muscle is detected, the command signal of the vertical EOG is ignored by the system. On the other hand, blinks in the EOG channel are rejected by the software because it does not reach the necessary threshold conditions and pulse width to be considered as voluntary.

Let $eog_1(l)$, $eog_2(l)$ and $emg(l)$ be the EOG vertical and horizontal signals, and the rectified EMG low-pass signal, respectively, with $1 < l < N$ and $N = 50$ (buffer or segment size, see section 2.A). Then, the majority vote algorithm from this segment is applied to the processed signals, that is,

$$M_1 = \left(\left(sum\left(eog_1(l) > Th_1\right)\right) > Mv_1\right) \& \left(\bar{M}_5\right) \qquad (1a)$$

where sum indicates the summation over the signal segment with $1 < l < N$; Th_i are the previously explained thresholds; Mv_i represent majority vote thresholds; M_i stand for classified results, and $i = 1,...,5$ correspond to upward, downward, leftward, rightward eye movements, and muscle activity (stop event), respectively. Besides, command signals $M_{i=1-4}$ from the EOG are ignored if EMG activity from M_5 is detected. The click event M_6 is determined from the M_5 stop event, and the previous stop M'_5 event. Because of physiological causes, $M_1 - M_2$ classified results and $M_3 - M_4$ are mutually exclusive. Finally, M is the vector of the arranged classified results.

Let $S = [y, x, c]$ stand for mouse states, i.e., the vertical and horizontal screen mouse positions and the click event, respectively.

The control algorithm of the HMI is defined as,

$$S = S + \Delta V\ M \qquad (3)$$

Where S is the mouse state, ΔV_i are gains, and M represents the classified results vector. The ΔV matrix are composed of several gains, as follows,

$$\Delta V = \begin{bmatrix} \Delta V_1 & \Delta V_2 & 0 & 0 & 0 & 0 \\ 0 & 0 & \Delta V_3 & \Delta V_4 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \qquad (4)$$

The vertical gains ΔV_1 and ΔV_2 were experimentally set at 3 and -3 pixels, respectively. In turn, the horizontal gains ΔV_3 and ΔV_4 were set at 6 and -6 pixels. Such gains determine a mouse velocity of $0.6\ ^{pixels}/_{seg}$ and $1.2\ ^{pixels}/_{seg}$. Even when those velocities may seem slow,

$$M_2 = \left(\left(sum\left(eog_1(l) < Th_2\right)\right) > Mv_2\right) \& \left(\bar{M}_5\right) \qquad (1b)$$

$$M_3 = \left(\left(sum\left(eog_2(l) < Th_3\right)\right) > Mv_3\right) \& \left(\bar{M}_5\right) \qquad (1c)$$

$$M_4 = \left(\left(sum\left(eog_2(l) < Th_4\right)\right) > Mv_4\right) \& \left(\bar{M}_5\right) \qquad (1d)$$

$$M_5 = \left(sum\left(emg(l) < Th_5\right)\right) > Mv_5 \qquad (1e)$$

$$M_6 = M_5 \ \& \ M'_5 \qquad (1f)$$

$$M = \left[M_1, M_2, M_3, M_4, M_5, M_6\right]^T \qquad (2)$$

this configuration adapted well to the volunteers' skills and the screen size, besides, it could be changed if necessary.

D. *Experimental Trials*

In order to test the system, several trials with 6 users were conducted, all healthy, with ages between 23 and 30 years old. Also, a female patient with end-stage multiple sclerosis tried the device and performed some activities. After informed consent, each subject was required to write the expression "*Hola Mundo*" (Hello World) using the Windows® virtual keyboard and then close this application positioning the mouse pointer on the right superior corner, refilling the dialog box to save the file. This test was repeated five times in order to measure the time it took to perform the task and conduct a study to determine the training impact. The multiple sclerosis patient's results were included in the next section, even though the words written were different.

The performance was evaluated with the index Λ, proposed by [19], such that $0<\Lambda<1$. This index is computed by (5), where n is the number of stages in the specific task; t is the time in seconds; h is a constant denoting the expected time for the task; gi indicates if the stage is complete or not (gi=1, if the stage's objective was reached, and gi=0 otherwise).

$$\Lambda = \frac{1}{n+1}\sum_{i=1}^{n} g_i + \frac{1}{n+1} e^{\cdot} \qquad (5)$$

Out of the 4 stages n considered by (5), two were assigned to writing *Hola Mundo*. The third stage was to close the virtual keyboard by means of x on the upper right corner, and the last was to save the file, as in any windows screen.

The expected time from this task was assumed to be 600 seconds, determined empirically, and based also on the average time obtained by the users. A stage was considered complete only if all letters were written, the window was closed in the first attempt, and the dialog box was completely refilled.

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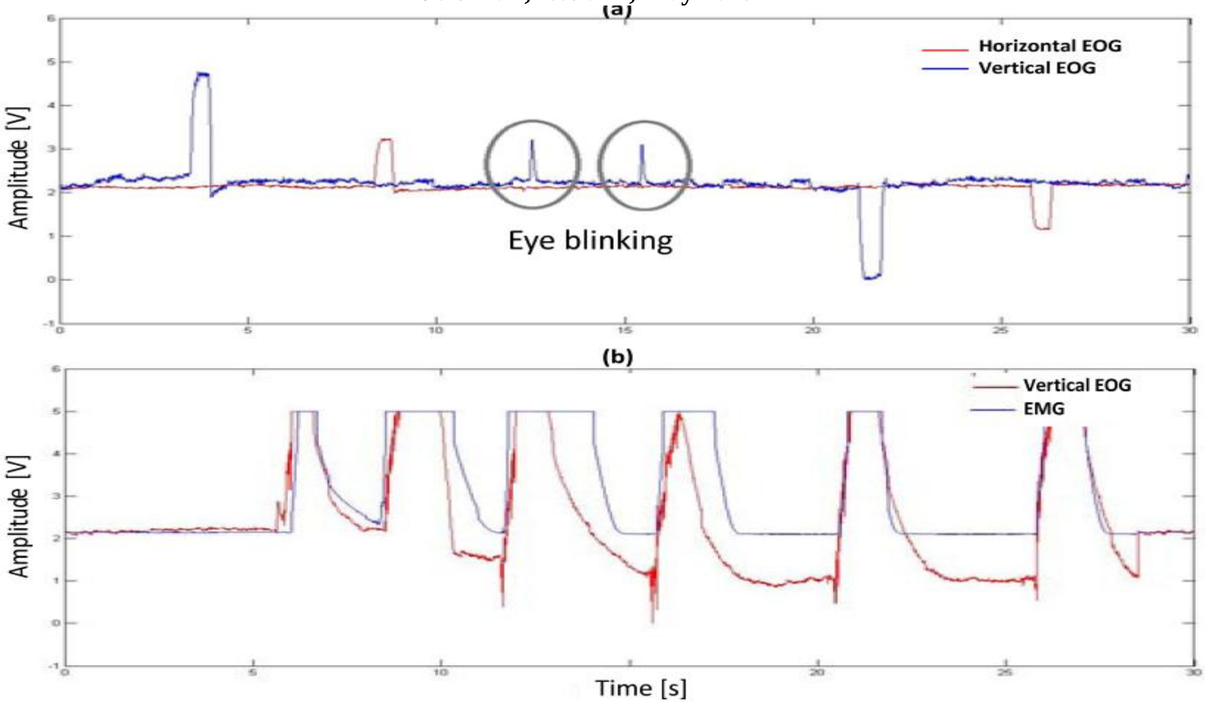

Fig 5. (a) EOG using the *Extreme Protocol* obtained during a sequence of upward-rightward-downward-leftward movements. Besides, blinks events were recorded and filtered by means of the control algorithm. (b) EMG (blue) and EOG vertical channel (red) registered in *frontalis* contraction.

III. RESULTS

Fig. 5 shows the signals obtained with the *Extreme Movement* protocol during a sequence. In the EOG it is possible to see the peaks, both on the vertical and horizontal channels. They have different characteristics, in amplitude and pulse width, as compared to the blink artifacts, allowing the discrimination of the voluntary commands to the mouse control. The EOG baseline is around the 2V of the offset signal, necessary for the microcontroller. Also, it is possible to see the processed EMG, superimposed to the EOG vertical channel. The algorithm selects EMG as priority signal, so avoiding the multiplicity of commands. To illustrate a complete sequence of movements, EOG and EMG signals were acquired during the action of closing a window, and moving the cursor to the top right hand corner. Fig. 6 depicts and fully explains the sequence of actions executed by the volunteer to carry the task out.

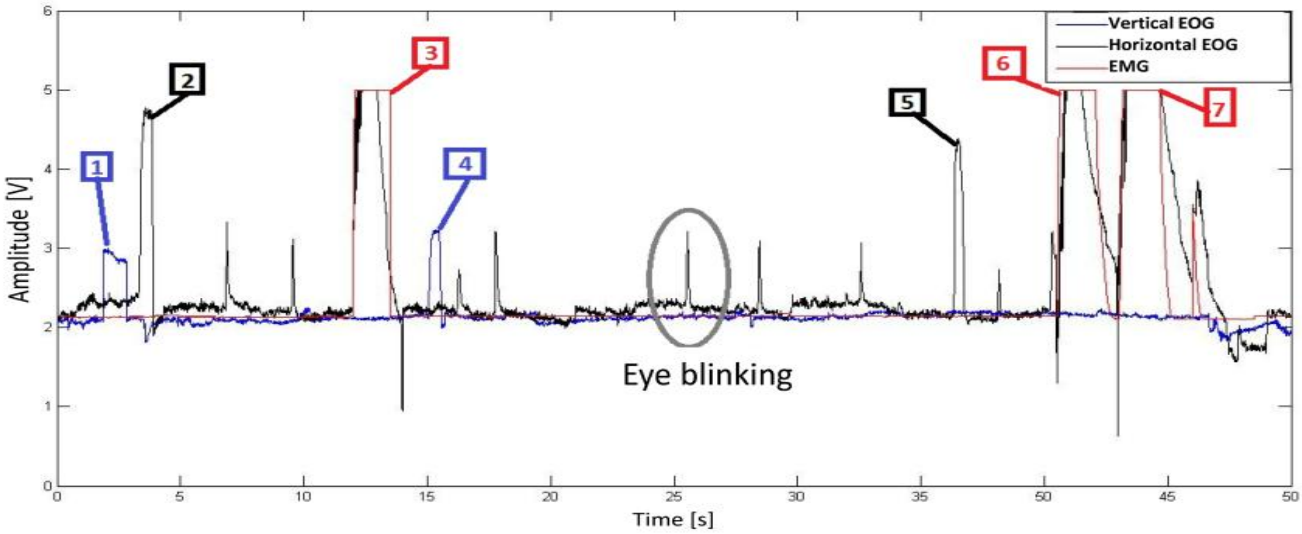

Fig 6: Sequence of actions to close a window. The horizontal EOG channel starts the movement to the right (1); the vertical EOG channel continues upward (2), composing a movement to the right diagonal. At (3), the EMG signal stops and the vertical EOG is discarded. At (4), the mouse restarts the movement to right, and upwards in (5). The EMG in (6) stops the mouse and the click action is prompted by (7). Blinks do not disturb the HMI control.

Fig. 7 present the time results for the 6 healthy users, showing the training impact and its time decrease. The data obtained in these tests show a reduction by approximately 50% in the tasks' execution times. While these durations may sound as excessive when one considers that only two words were written, it must be remembered (and also highlighted)

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the significant reduction as the user gained skill and became more familiar with the operation. The patient with multiple sclerosis requires an average of 28:46 minutes to write two words, tested in three trials.

The evaluation index proposed in Section 2-C was computed for all volunteers, showing an adequate performance, especially for healthy volunteers. The task was partially incomplete for the severely disabled patient, even when she expressed her acceptance of the device. Fig. 8 shows the index obtained with healthy volunteers, computed in the five trails.

The index highlights the importance of training, because it is substantially reduced as the number of trial progresses and provides a quantitative estimation of the user´s familiarity with the HMI.

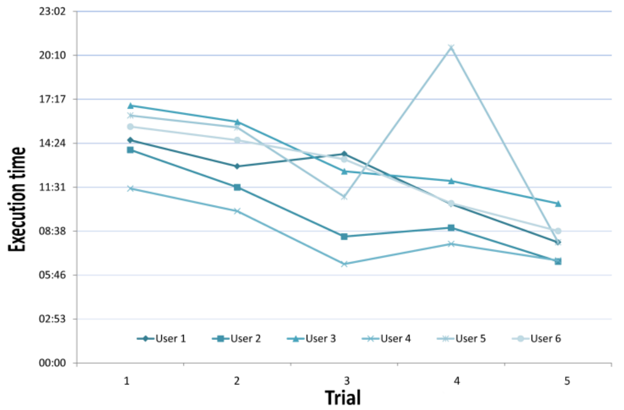

Fig 7.Time results for the 6 healthy volunteer in Table I. Decrease of the time taken for accomplishing the tasks denotes the training impact.

IV. DISCUSSION AND CONCLUSIONS

We have presented a wearable hybrid human-machine interface, based on EOG and EMG. The device was designed with the aim of restoring some communication abilities to severely disabled patients, not able of moving either their limbs or head or both. The HMI was tested in terms of user´s acceptance, performance, size, portability, and data transmission. The wireless communication provides electric safety conditions and comfort, and the XBee® transreceivers were considered as the best option because of its low energy consumption. The filters designed reduce the power line noise preserving the information contained in the EOG and EMG signals, allowing the cursor control without loss of performance and total screen excursion.

According to their abilities, the users can select the threshold between five levels of sensitivity, to suit their requirements and also load, modify and save their profiles. This choice allows the user to make smooth eye movements, such as reading or look outside the screen. The latter, though, will not be considered as a control signal (or which will not interfere with the control commands).

Neural networks classifiers and other signal processing techniques, such as wavelets, nearest neighbourhood algorithm and derivative process [11]-[20]-[21] have been used to process EOG signals with a high level of accuracy (around 90% in the cited references). The algorithm herein proposed does not require a PC based classifier, reducing the computational cost and embedding the entire decision process in the Arduino board. This feature provides versatility when facing different operating systems and assistive software.

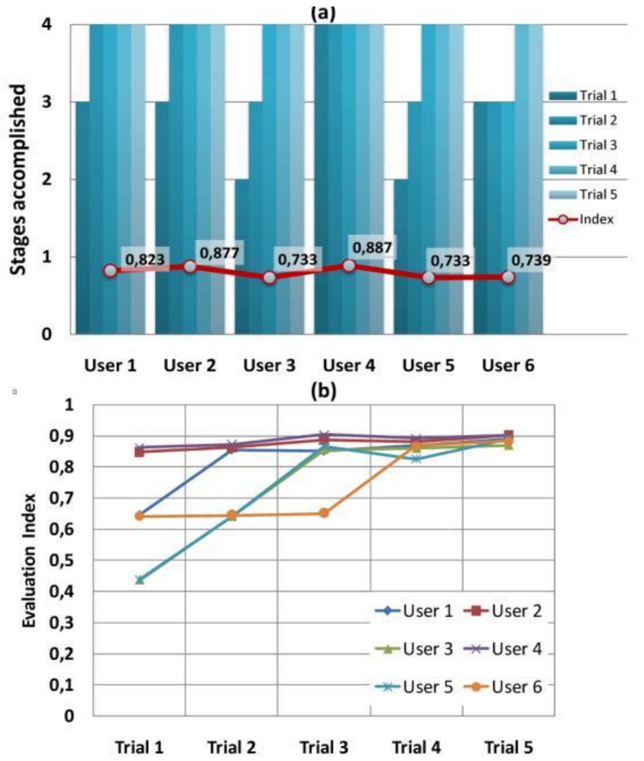

Fig 8 (a) The graphical bar exposes evaluation index average values, and stages accomplished in each one of the five trials. The number of complete stages increases with the number of trials. (b) The evaluation index increases with the progress of the experiment, showing the training impact as the trial progresses.

Several trials have been made to evaluate the HMI, obtaining satisfactory velocity indexes and user's acceptance, as can be seen in the results section. In other reports, this action depends on blinks or eye-movement codification, which adds complexity to the user. We propose a hybrid concept that improves accuracy in the click action due to the EMG command. A training stage is necessary for a complete HMI domain, especially for patients with severely diseases. From the results obtained in the experiments, it can be seen that all users reached the objective at the fifth attempt. It is hence demonstrated the training impact importance, although the number of necessary trials does not seem a limiting factor. The time spent to carry out the task decreases while the user acquires more familiarity with the HMI, which is another training and reliability feature. The patient with multiple sclerosis was a challenge to the HMI design, due to the advanced stage of the disease. The device was used as a communication alternative for the patient, and we deemed the results as satisfactory. As pointed out in [20], it does not yet exists a test accepted by researchers to measure and compare the results of EOG-based systems. The performance evaluation and accuracy vary when different papers were checked. Thus, and concluding, we propose a quantitative index of performance with the aim of standardizing the assistive technologies evaluation.

Futures enhancements will include glasses with mounted electrodes, a more portable system and dedicated software for accessibility and communication.

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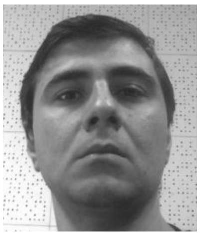

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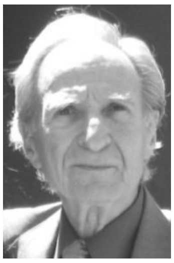

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