Human-Machine Interface Based on Muscular and Brain Signals Applied to a Robotic Wheelchair

A Ferreira, R L Silva, W C Celeste, T F Bastos Filho* and M Sarcinelli Filho
Electrical Engineering Department, Federal University of Espirito Santo (UFES),
Av. Fernando Ferrari, 514, Vitoria, 29075-910 – Brazil.

*E-mail: teodiano@ele.ufes.br

Abstract. This paper presents a Human-Machine Interface (HMI) based on the signals generated by eye blinks or brain activity. The system structure and the signal acquisition and processing are shown. The signals used in this work are either the signal associated to the muscular movement corresponding to an eye blink or the brain signal corresponding to visual information processing. The variance is the feature extracted from such signals in order to detect the intention of the user. The classification is performed by a variance threshold which is experimentally determined for each user during the training stage. The command options, which are going to be sent to the commanded device, are presented to the user in the screen of a PDA (Personal Digital Assistant). In the experiments here reported, a robotic wheelchair is used as the device being commanded.

1. Introduction
The interest in biological signals has increased significantly in the last years, due the possibility of getting information from them, which can help to express some desires of a person with a severe motor dysfunction. There are cases in which the conventional communication channels are completely unavailable, e.g., when an individual has lost the ability to speak and move his/her arms. However, it is common that such a person keeps his/her cognitive capacity. People with Amyotrophic Lateral Sclerosis, brain stroke, cerebral palsy, spinal cord injury, muscular dystrophy and other types of disabilities present such symptoms.

Human-Machine Interfaces (HMI) has emerged as viable communication channels between a person having a severe dysfunction and the world around him/her. Such systems use the biological signals voluntarily generated by the individual, which can be derived either from a muscle of the human body or the brain activity, and are acquired through surface electrodes. Brain signals are used only when it is not possible to use muscular signals (the individual has not voluntary muscular movement). In that case, the HMI should look for patterns associated to the brain activity, which are captured through an Electroencephalogram (EEG), according to [1], [2] and [3].

HMI systems were used in previous works to command robots. In [4], for instance, it is presented a HMI used to command a mobile robot, while in [5] another one is used to command a robotic manipulator. This work shows an improved version of the HMI developed in [4] and [5], now applied to a robotic wheelchair. The structure of such a system is presented in Section 2, while Section 3 details the signal acquisition and processing subsystems. Following, Section 4 presents the accomplished experiments, and, finally, Section 5 highlights some conclusions and future works.
2. System Structure
The system reported here is a Human-Machine Interface used to command a robotic wheelchair. A block diagram representation is presented in figure 1, which shows the system architecture responsible for acquiring and processing the biological signals. The processing system includes signal filtering and amplification in the desired frequency band. Right after, such signals are digitalized and sent to a computer, where they are filtered again (to select the desired frequency band) and the features of interest are extracted. A classification step is performed, regarding such features, where is verified whether the signal is voluntary or not, and the pattern identified is associated to a command. The computer communicates with a PDA, which works as an audio-visual feedback device, notifying the user intention of selecting the option displayed in the screen of the PDA. If such option is related to the wheelchair, it is sent back to the computer, which generates the control signals to move the wheelchair. On the other hand, the selected option can be referred to the communication interface between the user and the world around him/her, thus not being necessary to move the wheelchair.

3. Signal Acquisition and Processing
The signal acquisition procedure begins with a good placement of the surface electrodes. For acquiring the muscular signal (EMG) caused by eye blinks, the electrodes are placed over the temporal muscles. For brain signal (EEG) acquisition, instead, the electrodes are positioned over the occipital region of the brain cortex, where the signals have higher energy during a certain brain activity. In this case, the surface electrodes are placed in the positions O₁ and O₂, established by the international 10-20 standard as according to shown in figure 2.

Figure 1: The structure of the developed HMI.
The current system version has two analog channels for signal input, and both EMG and EEG signals are used to command a robotic wheelchair. The EMG signal is produced in connection to eye blinks. The electrodes are placed on the forehead of a person, with a reference electrode in the earlobe. Figure 3 shows where the electrodes are placed, in such a case, providing an acquisition channel for each eye muscle signal. It also shows typical eye-blink signals. The signals shown are the difference between the two channels (differential signal). Thus, when the user blinks the two eyes, the corresponding signals are subtracted one from another, which results in a negligible signal, while blinking just one eye results in a meaningful signal, as shown.

The EEG signals used are generated by the brain activity in the occipital lobe, that is, the part of the human brain responsible for processing the visual information. Therefore, the electrodes are placed at the O1 and O2 positions aforementioned. The features used are the suppression and the activation of the alpha rhythm, which are related to concentration or visual excitation (the signal energy is lower when the eyes are opened) and visual relaxation (the signal energy is higher when the eyes are closed). Figure 4 shows the electrodes placed over the scalp of an individual, in the occipital region of his brain cortex. It also presents an EEG sample of such an individual, illustrating a visual excitation (suppression of the alpha rhythm) followed by a visual relaxation (activation of the alpha rhythm).

The signal acquisition subsystem has a pre-processing stage where the signal is filtered, amplified and digitalized. The signal digitalization is done through an A/D conversion board based on the AD7716 chip, which possesses 22 bits, four analog input ports, sampling frequency of 140 Hz and for which the frequencies of the signals can range from 0.5 to 32 Hz.

![Figure 2: The international 10-20 standard for electrode placement.](image)

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![Figure 3: Acquiring the EMG signal caused by eye-blinks.](image)
In the pre-processing of either the EMG or the EEG signals, the DC level, the 60 Hz noise, the noise caused by bad electrode placement and other spurious signals (such as artifacts of muscular and cardiac origins) are discarded. In the specific case of EEG signals, the signal, thus obtained, is filtered by a FIR digital filter whose bandwidth is just the EEG alpha band (8-13 Hz).

Feature extraction is the step performed just after the signal pre-processing. In this work, the signal variance is the feature of interest. Regarding the signal samples contained in a window of length $N$, such a variance is given by

$$\sigma^2 = \frac{1}{N} \sum_{k=1}^{N} (x_k - \mu)^2,$$

where $x_k$ is the $k$-th signal sample inside the window and $\mu$ is the average value of the signal samples inside the window, which is given by

$$\mu = \frac{1}{N} \sum_{k=1}^{N} x_k.$$

It is worthwhile mentioning that in this work the window length $N$ adopted is 280, which was empirically selected, after analyzing a set of EEG signals processed using distinct window lengths. Moreover, such a window is refreshed each time a new signal sample arrives, so that the values of $\mu$ and $\sigma^2$ are functions of time.

The upper part of figure 5 presents an example where the signal containing the patterns corresponding to the suppression and the activation of the alpha rhythm. In order to generate that specific signal, the individual begins with his/her eyes opened (suppression) and next closes them (activation). In the bottom part of such a figure, it is shown the corresponding signal variance.

The classification step is performed with basis in two thresholds, a low one and a high one, whose values are adjusted during the training step. Thus, when the variance is smaller than the low threshold, the system does not identify a command. On the other hand, when the variance is greater than the high threshold, the system identifies that the user has defined like a command. Thus, the user should be able to produce a transition from the situation of suppression to a situation of activation of the alpha rhythm (by closing his/her eyes). Otherwise, if the signal variance is in between the two thresholds, the HMI does not detect the intention of issuing a command.

This way, a person with severe motor dysfunction who preserves the ability of manipulating the alpha rhythm can control an assistive system. In this work, it is presented a graphic interface controlled by EMG or EEG signals, which augments the communication ability or allows the user to control assistive equipments, such as a wheelchair. This is performed through using pictographic symbols (or icons) presented in the screen of a PDA, in connection to acoustic output speakers. Such icons are associated to pre-defined actions, such as some specific movements of the wheelchair (move ahead, move back, turn left, turn right, rotate left and rotate right), some expressions of personal necessities or feelings (itch, pain, thirst, hunger, desire to go to the toilet, etc) demanding external assistance, or selection of characters to exchange messages with people around.

Figure 6 depicts three different screens with some of the options the user can choose, each one represented by an icon. The PDA is installed just in front of the user’s head, and its screen is permanently exhibiting one of the possible set of options (which can also be changed by the user.
through the HMI). Each icon in the screen currently exhibited is emphasized for a while, through an automatic sweep system. Thus, when the desired option is emphasized, the user blinks the eye (in the case of muscular signal acquisition) or closes both eyes (in the case of EEG acquisition). As soon as the system identifies the selection the user made, a sound is emitted and the current icon changes its emphasizing color. Experiments showed that the sound feedback allows the user to achieve a better performance when selecting the desired option, mainly when using EEG signals, because, in this case, the individual keeps his/her eyes closed for a while, what can cause anxiety, thus affecting the capacity of controlling the HMI. After an option is selected, the automatic sweep system starts again, waiting till the user selects another option.

4. Experiments
The HMI is used here to command a robotic wheelchair (figure 7). Such wheelchair has two independent electrically driven wheels. Encoders installed on the axes of the two motors allow knowing the relative position and orientation of the vehicle.

In figure 8 can be seen a person controlling the robotic wheelchair through using the HMI here discussed. In the experiments accomplished, the person used both EMG and EEG signals to command
the vehicle. In order to capture that signals, disposable electrodes were used, which should be fixed
over clean surfaces. In addition, it is necessary to apply a special gel between the skin and the
electrode for reducing the contact impedance. Such cautions should be very carefully taken into
account in the case of EEG acquisition, because the EEG signals have magnitudes that are much
smaller than those of the EMG signals.

Figure 9 shows a graphical interface used for analyzing the acquired and processed signals during
the training step and the HMI development. It shows the raw captured signal, the filtered signal and its
variance, at the top, intermediary and bottom screen areas, respectively. The bottom screen area also
shows the two thresholds used for detecting the intention of selecting an option, which are defined for
each user during the training step.

Five healthy persons were invited to command the robotic wheelchair and all of them were
successful after just a few minutes of training. The procedure the user followed to select an icon
presented in the screen of the PDA, when using EEG signals, was as follows: when the desired icon is
emphasized in the screen, the user closes the eyes; when the user listens to a characteristic sound
he/she opens the eyes; if the option just selected is a wrong one, the user just closes the eyes again to
cancel the last selection. Otherwise, he/she should keep the eyes opened waiting till another desired
option is emphasized by the automatic sweep.

Finally, it was observed that in order to generate a brain signal through processing visual
information it is not necessary that the user effectively closes the eyes. It is enough to interrupt the

Figure 7: The robotic wheelchair used in connection to the HMI.

Figure 8: Robotic wheelchair commanded by a user through the proposed HMI.
passage of light with a dark paper. So, in the experiments, it was verified the activation of the alpha rhythm while the person kept the eyes opened, just preventing him/her to receive the light stimulus, which allowed selecting an icon in the screen of the PDA even when the user kept the eyes opened. This is an interesting result that suggests the muscular signal caused when the user blinks both eyes in order to allow selecting an icon does not cause interference in the EEG signal.

5. Conclusions and Future Works
The HMI here addressed has proven to be quite efficient to detect both muscular (eye blink) and brain (eye opening and closing) signals. The system was tested by volunteers who could command a robotic wheelchair after about five minutes of training. All these volunteers were healthy individuals, although the system has been designed for people suffering from severe muscular diseases. So, the next step of the research is to test this system considering this public. However, it is necessary to assure that the system is safe when regarding some possible dangerous situations, regarding the physical integrity of the user. It is also very important to take care of avoiding frustration or great expectation by the user, through making clear that the proposed system is still a prototype, not a commercial platform.

Several works are been developed aiming on improving the system so far developed: more options of selection are being considered and safety is being worked on for future tests regarding users suffering from motor dysfunction. Also, new possibilities to command the wheelchair are being developed, such as an eyeball movement capture system using a camera (Video-Oculogram – VOG) and a system based on brain signals capable to detect the movement intention of some part of the body (like hand, arm, etc). In the last case, the brain signals must be captured using electrodes installed in the C3, Cz and C4 positions (see figure 2), in order to monitor the brain activity associated to the motor cortex. Finally, it is being developed a system capable to allow the wheelchair to receive high level commands such as “go to the bedroom” instead of simply “go ahead”.

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Reference
[1] Wolpaw J R, Birbaumer N, McFarland D J, Pfurtscheller G and Vaughan T M 2002 *Brain-Computer Interfaces for Communication and Control* (Clinical Neurophysiology), pp 767-791.
[2] Lehtonen J 2003 *EEG-Based Brain Computer Interfaces* (Master Thesis, Helsinki University of Technology).
[3] Millán J, Renkens F, Mouriño J and Gerstner W 2003 *Non-Invasive Brain-Actuated Control of a Mobile Robot*, in Proc. of the 18th International Joint Conference on Artificial Intelligence (Acapuco, Mexico).
[4] Frizera-Neto A, Celeste W C, Martins V N, Bastos Filho T F and Sarcinelli Filho M 2006 *Human Machine Interface Based on Electro-Biological Signals for Mobile Vehicles*, in Proc. of the International Symposium on Industrial Electronics – ISIE 2006 (Montreal, Canada) pp 2954-2959.
[5] Ferreira A, Bastos Filho T F, Sarcinelli Filho M, Auat Cheein F A, Postigo J and Carelli R 2006 *Teleoperation of an Industrial Manipulator Through a TCP/IP Channel Using EEG Signals*, in Proc. of the International Symposium on Industrial Electronics – ISIE 2006 (Montreal, Canada) pp. 3066-3071.