EMG AS A DAILY WEARABLE INTERFACE

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Abstract: We present electromyography as an interface to control computer applications. Our prototype makes possible for users to control any application through muscle contractions. Electromyographic device portability and the monitoring possibility for any muscle voluntarily contracted can bring great benefits at the mobility level as in accessibility issues. Through operating system events emulation and their association with determined muscle contractions we can replace the pointing device or some keyboard elements, achieving control of any application.
Usability evaluations validate electromyography as a daily wearable interface where we show that it can be used even in a mobility context. Considering accessibility, we present a synergy between applications that ease message writing. Evaluations show that this synergy outperforms existent text-entry interfaces, based on point and click approaches.

1 INTRODUCTION

We are used to communicate with the computer through the use of the keyboard, pointer devices or even by speech. All those paradigms are based on our senses. The human body is far more active and reactive than that. It is composed by cells, tissues and organs which change their behavior when stimulated. This takes us to the study of physiological signals to increase our communicative and interactive capabilities. We have focused on electromyographic signals.

Electromyography (EMG) is defined as the study of the muscular function through the analysis of the generated electric signals during muscular contractions. The potential difference obtained in the fibres can be registered in the surface of the human body through surface electrodes due to the biological tissues conducting properties.

Our project studies the muscular activity as an input in order to control applications. A large set of target muscles are available so we can interact widely with the computer. The main goal of the project is to provide tetraplegic individuals the capability to control a portable device (specially to be able to write and send SMS). In order to accomplish this task we monitorize muscle activity through an electromyographic portable device, process the digital signal and emulate certain events accordingly to the features detected. Being able to detect and to evaluate muscular activity in an individual gives us the possibility to associate it with determined interface commands, thus having the myographic signal as input. This kind of interaction can also be useful to full capable individuals in a hands-busy situation, such as in a presentation or in a mobility context.

1.1 Related Work

The recurrent and increasing electromyography study in medicine related areas led to a great scientific investment to improve the myographic signal acquisition and analysis process. These advances culminate with the possibility to use portable electromyographic devices that communicate via wireless with a processing system. Portability makes it possible for any individual the transport and use of a EMG device with great social acceptance (Costanza et al., 2004). EMG devices portability and reduced size easily conducted to its use in HCI with work carried through in the area of Accessibility, Robotics, Mobile Computation and Recognition of Gestures, among others.

(Roy et al., 1994) present a gesture-based person-

machine interface for people with serious motor limitations due to cerebral paralysis. This work, based on gestural recognition with biomechanic and bioelectric sensors, present many motivating results being capable to differentiate gestures through the use of neural networks. In the same scope, (Barreto et al., 1999) introduce a system that tries to offer the users with serious motor limitations the possibility to use the traditional interfaces to point and select. This system associates face movements to mouse control, being sufficiently similar to the system "Tongue Point" (Salem and Zhai, 1997) but using myographic signals. It is still in the accessibility context that (Eriksson et al., 1998) lean over prosthesis control. Their work looks for exceeding hand prosthesis existent limitations when compared with the freedom presented by a full capable hand. The authors show that through the training of neural networks with a operating hand they can classify the intention to make movements in the prosthesis and with that intention they can improve the prosthesis mechanics.

(Costanza et al., 2004), (Costanza et al., 2005) give emphasis to the EMG usability evaluating it as a mobile interaction technique.

There are some other relevant projects that use an EMG device to control mouse, joystick or keyboard or a specific application that influenced positively the developed work (Benedek and Hazlett, 2005), (Coleman, 2001), (Crawford et al., 2005), (Jeong and Choi, 2003), (Manabe et al., 2003), (Rosenberg, 1998), (Surakka et al., 2004), (Tanaka and Knapp, 2002), (Wheeler and Jorgensen, 2003).

Despite of the scope, all the projects refereed intend to present EMG as an input interface. In this article we present our results and present user studies to go further and validate electromyographic devices as daily wearable interfaces. Our prototype accomplishes the control of various computer applications and introduces a synergy between applications that ease the text-entry task. In the next section we present our approach. The other sections are focused in the user evaluations, results and discussion. In the last section we present the conclusions taken by the user evaluations along with the work still to be done.

2 PROTOTYPE

We present a system where one can control computer applications through muscle contractions. For that purpose we need to collect the myographic sinal, process it, extract features and create some sort of action. In the following sections we make a detailed presentation of our work.

2.1 EMG Portable Device

Our electromyography device collects samples at a 1000Hz sampling rate in 5 independent channels. It has a 110dB CMRR amplifier and a band pass filter between 25 and 500 Hz with gain 1000. It is a relatively small device (14cm * 8cm * 4cm) that can be carried in a belt or pocket.

It is a portable device which communicates by a bluetooth interface within a 100 meters range. To collect the signals we use surface differential electrodes, with 1.5 cm radius (Gamboa et al., 2004)

Figure 1: EMG Portable Device

2.2 Signal Recording

In order to get useful information concerning the muscular activity it is necessary to carefully analyze some aspects, from technical details at the electrode placement in the surface of the human body to the points where this placement must be done. Several aspects influence the signal quality: skin preparation, electrodes placement position, electrodes fixation, electrodes distance and outside interferences (De Luca, 1997).

We have discarded all the skin preparation techniques since we don't think they are appropriate to an user interface. Besides, after several tests we observed good signal quality with small interference. However, to reinforce the surface electrodes adherence we created an elastic band for the neck and two elastic bands for the forearm.

We used the 2cm distance between electrodes which guarantees a solution of commitment (Figure 2), collecting the signal of a significant portion of the muscle and restricting, simultaneously, the undesired signals to insignificant values (De Luca, 1997).
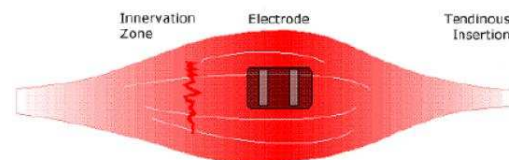

Figure 2: Electrodes placement

Basically, the electrodes can monitorize any voluntarily contracted muscle. However, the signal fre-

quencies and amplitudes are somehow different between muscles. Figure 3 presents the electrodes position options in a frontal view. It shows surface electrodes placement position in the right side and deeper needle electrodes positions in the left side. Obviously, we only use surface electrodes as we are studying a wearable daily interface and want to keep users far from pain.

The electrodes shouldn't be placed in the motor point where it verifies a damping of the signal low frequency components. Besides the electrodes placement position it is also important to concern the orientation of the electrodes in relation to muscular fibres (Figure 2). The imaginary line that joins the two surfaces must be parallel to the muscular fibres orientation.
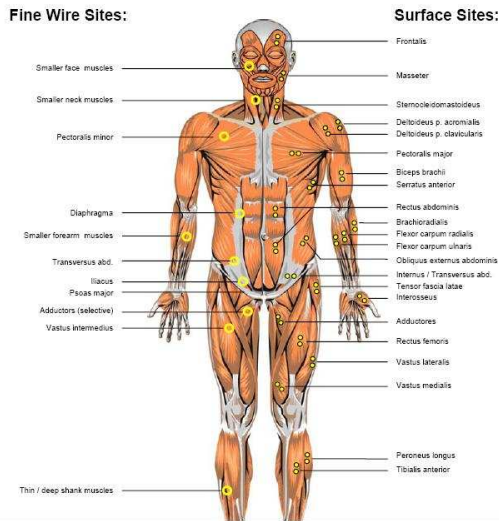

Figure 3: Electrodes frontal possible positions

2.3 Signal Processing

In order to extract useful information from the digitalized signal we need to process it. Our signal processing module is composed by a pre-processing and a smoothing phase.
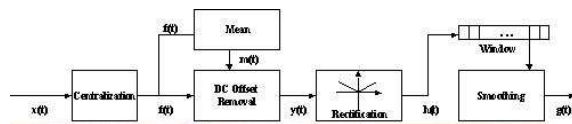

Figure 4: System Design

The pre-processing is composed by some basic procedures that prepare the signal to be smoothed. The signal received from the electromyography device has a gamma of values between 0 and 4096, having this to be adjusted, since, really, the signal oscillates between negative and positive values. The centralization is a very basic operation and consists of deducting the base value (2048) from the signal. After that, we add the value to the set of received values already acquired and, with the average calculated on these, we calculate and remove the DC offset, normally existent in EMG signal:

$$y(t) = f(t) - m(t) \qquad (1)$$

Finally, we rectify the sample. The curve rectification is an operation normally used to allow the posterior signal integration, since it transforms a curve with positive and negative values, averaging zero, in a curve of absolute values, all positives. Two forms of rectifying the curve exist: eliminating the negative values ("half-wave rectification") or adding them to the positives ("full-wave rectification") (Correia et al., 1992). The last process is preferable since it keeps all the signal energy:

$$h(t) = |y(t)| \qquad (2)$$

In order to smooth the signal, we carried through an average on a sliding window, keeping in the output the same number of collected samples, but now having in consideration the neighboring" samples:

$$g(t) = \frac{1}{N} \sum w(i) \qquad (3)$$

where N is the window dimension.

We experimentally observed 50 ms as a fine window dimension value as it keeps the real time impression and smoothes the signal as desired. Upper values improve the signal quality but decrease the response speed. Figure 5 presents the signal evolution through the referred filters.

2.4 EMG Onset Detection

The projects mentioned in this area have strong pattern classification algorithms that give them great reliability but as drawback they need long training sessions for each user. In our work we try to make a simpler approach adaptable instantly to every user with no training required, which we think is a major advantage. In order to detect muscle onset we could use a fixed threshold value but soon questioned this approach since the activation value is quite different between different persons, muscles or even in different days. It is very difficult to keep the exactly same setup. Our system detects onset detection with an approach where threshold is estimated as a multiple h of standard deviations (Staude et al., 2001).
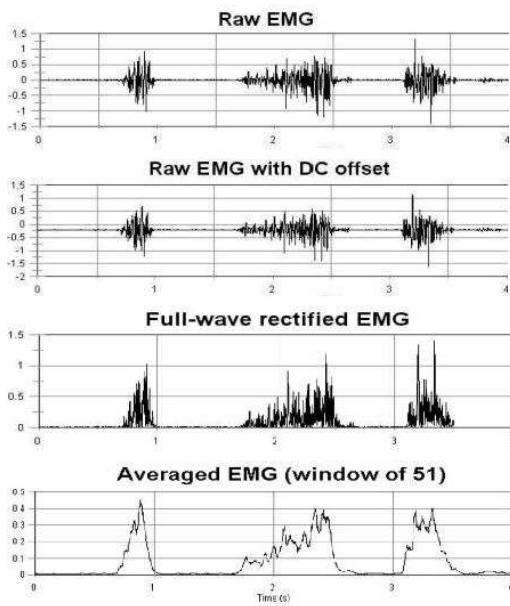
Figure 5: Signal Processing

2.5 Event Generation

Instead of keeping our application enclosured we thought it would be advantageous to be able to control any computer application with the interface created. With that purpose, our prototype acts like a background monitor that processes the signal and as muscle activations are detected it launches operating system events (mouse movements, mouse clicks or keyboard events). The user can set up the events for any input channel. As we simulate operating system input events they can be used in any active application. With this system we can control the "Desktop", open applications, work within those applications, and change between them, as long as they have a limited number of input events. It can actually be used in a Linux or Windows desktop. Full desktop control is achieved.

3 METHODOLOGY

We conducted several experiments to assess the usability of myographic activity as as interaction modality. For that purpose, besides the experiments to validate the interaction speed and accuracy, we focused our attention in the interface robustness as a daily wearable interface.

3.1 Speed and Accuracy

In order to evaluate the speed and accuracy of our prototype and validate EMG as an input interface we developed a simple test application. It is quite similar to the one used by (Barreto et al., 1999) and consists in a point and click timed exercise. The setup is created with enough electrodes to emulate mouse moving directions and left-click.

We developed a simple OpenGL application with a Start Button (presented in a corner position) and a Stop button presented in the middle of the screen. The experiment consists in:

a) Clicking Start Button, where a timer is activated;

b) Moving the cursor towards the Stop button, with any trajectory;

c) Clicking Stop Button, and the time is presented to the user and saved.

The Start Button dimensions are always 8,5 x 8,5mm but there are four Stop Button dimensions (8.5 x 8.5mm; 12.5 x 12.5mm; 17 x 17mm; 22 x 22mm). We made 80 evaluations, 20 of each for every Stop Button size. The Start Button changed between the four corners.

The users were equipped with two pairs of electrodes in each forearm (four directions) and another pair near one eye to detect blinking (click emulation).

3.2 Wearability

(Costanza et al., 2005) give relevance to EMG technology in the context of the mobile computation mentioning it as a subtle interface translated in a great social acceptance. They are based on the fact that individuals who use the system are able to interact privately without disrupting the environment that encircles them. This work is mentioned by the motivational ideals related to the use of EMG with mobile devices. It evaluates the EMG usability while walking and making contractions of different durations. However, (Costanza et al., 2005) use only one input channel for simple subtle intimate response events. Our evaluation method tries to validate EMG wearability and mobility but with a more complex prototype where there are several monitorized input channels/muscles and several corresponding actions previously selected. The aim of this experiment is to evaluate if the system responds as it is expected even in standing and walking conditions.

To evaluate the system's correct response we designed a walking circuit (similar to Constanza's) which the user has to follow as he responds to orders. Several variants were tested from the Walking with no contractions setup to the walking with 4 contractions involved. The variations are:

- Walking with no contractions.

- Standing with stimulus response.
- Walking with stimulus response.

The users were equipped with two pairs of electrodes in each forearm (four directions) and another pair in one eye's zone (click). Another setup was created with one pair of electrodes in each side of the neck (Figure 6). The first setup is directed to mobility issues as the second is directed to quadriplegic users.

Figure 6: Electrodes placement

3.3 Daily Control

Electromyography can bring great benefits in situations where the traditional input devices are not available. They could be unavailable due to individuals impairments or to the situation context.

Concerning accessibility, we can look at EMG as a wide alternative since it can explore any voluntarily contracted muscle. Thinking in quadriplegic,i.e. we can attach surface electrodes to their neck and make possible a pointer control in a computer.

Concerning full capable individuals in a hands-busy context we can look at EMG as an alternative to control a mobile device.

There are great benefits in EMG as a daily control interface but we need to validate its use. To evaluate the continuous use of our prototype (several hours) we asked the users to control the pointer device in the computer with muscle contractions. With that purpose and to detect any failure we removed the user's regular pointing device.

The users were asked to interact freely with the computer for two hours. We asked for regular activity demanding several movements and clicks. This experiment evaluates the prototype's usability and the EMG signal quality in a large time-scale.

This evaluations were performed with the two electrodes placement setups already refereed (forearm and neck).

3.4 Dasher and Accessibility

The main goal of our research around electromyography is to provide a writing mechanism for quadriplegic users. This capability will be merged with the control of mobile devices main tasks. In general, projects around EMG bet in a point and click approach, which is inappropriate to the writing activity (very slow). We purpose a synergy between applications where a pointer is continuously controlled by myographic activity, which appears to be a faster and efficient approach. Dasher (Ward et al., 2000) is a text-entry interface based in a zooming technique. This application was developed considering situations or users associated with an incapability to write in a keyboard. The user basically navigates in a "sea of letters" which appear accordingly to word prediction techniques. It allows two-dimensional and one-dimensional control.
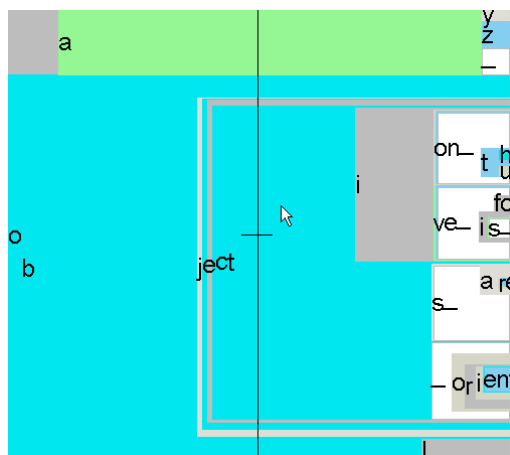

Figure 7: Dasher Application

The users were asked to write the sentence "Dasher is a fine text entry interface and I enjoy it". This evaluations were performed with the forearm setup and neck setup (Figure 8) with only two electrodes as the application gives the one-dimensional control possibility.

We also tested the forearm position setup and asked the users to write the sentences using Windows On-Screen Keyboard to compare our synergy navigation application with point and click approaches. We used the same goal sentence.

4 RESULTS

The tests were carried through in a Pentium IV portable computer, with 512 MB RAM and a 17" color monitor. To collect the real time signal we

Figure 8: Neck Elastic Band

used the electromyographic device described in Section 2.1.

The system was tested with three subjects, with 19, 24 and 51 years. All of them were used to deal with computers. The studies took several hours with each user because we needed to test the system and the paradigm robustness. The presented results are also preliminary as we want to focus our development in accessibility, and so further user evaluations will be effectuated with tetraplegic individuals.

4.1 Speed and Accuracy

Table 1 shows the average values taken for each subject to complete the 80 trials. The subjects required an average of 7.5 seconds to achieve the experience goal.

Subject	1	2	3
Average Trials Time (s)	7.505	6.982	7.903
Standard Deviation	2.805	2.345	3.014

Table 1: Speed and Accuracy trial times

Before the experiment the users familiarized with the system for two minutes. Familiarization was a very fast task since the users understood the relation with the mouse movements normally executed.

This experiment gave the users the necessary control of the device to complete further evaluations.

4.2 Wearability

This experience intended to test the system in standing and walking conditions while responding to voice impulses. The users were already familiarized with the system due to first experiment trials.

One of the users had one false positive in the Walking with Stimulus Response task. The other two had no false positives. The false positive was due to wire misplacement. No false negatives were detected in any of the users' experiments.

4.3 Daily Control

The results to this test are only qualitative. The users achieved total control of the interface and performed their usual tasks (Web Browsing, Messaging, Document Opening and Closing,...). Some of them noticed mouse right-click missing. They also noticed a lack of productivity since they couldn't get the same performance as in their usual interaction mode. However, the users were impressed with the control achieved by the interface and found it usable. In the pos-analysis we noticed an improvement of the signal quality (less noise).

4.4 Dasher and Accessibility

The experiment results are presented in Table 2. In order to understand the evaluation we need to define exactly the meaning of every metric:

- Error: an error is detected when the user misses a letter and has to come back. Some of these errors may be users fault, i.e. skipping a letter or a space by distraction.

- Time: time until the user ends his sentence correctly.

Task	Errors	Time(s)
Dasher/Forearm	0.00	124
Dasher/Neck	0.33	200
On-Screen Keyboard/Forearm	0.33	480

Table 2: Average Text-entry trial results

All the users succeeded and were capable to write the entire message. The errors detected were related to user's distraction, i.e. skipping letters and having to go back in the writing. There were no errors in the forearm control + Dasher task. One of the users made an error in the neck control (missed a letter) but was capable to go back and complete the trial. We had one error in the On-Screen Keyboard (hitting between letters).

5 DISCUSSION

The results obtained in the several experiments present Electromyography as an alternative interface to the traditional ones.

Our approach seems to be quite efficient compared to others, i.e. in the Speed and Accuracy test we duplicated an experiment already made by (Barreto et al., 1999) and the results are quite better. The subjects in our trials required around 7.5 seconds to move the cursor from the corner button to the center button

and performing a Left-Click as Barreto had an average result of 16 seconds. One of Barreto's suggestion was to use the prototype with On-Screen Keyboard to entry text. We presented a synergy between applications that outperforms the On-Screen Keyboard scenario: our approach averaged 124 seconds against 480 seconds in the keyboard. Both the Speed as the Dasher results are quite interesting and present electromyography as an auxiliary interface for impaired individuals. These tests included the writing through neck movements which were successful. Electromyographic interaction is an opportunity for tetraplegic individuals and we improve this opportunity with a faster and accurate approach.

Our test users used the system for hours and evaluated its daily utilization. Even if it is slower than their normal input devices it is certainly viewed with another enthusiasm by people incapable of using keyboard or normal pointing devices. Nowadays, eye-trackers already provide this kind of control for users with special needs but, although they present a faster movement of the cursor, they also present serious limitations like the difficulty to accurately control the cursor, or its loss of calibration during use. The cost of an Eye-tracker is also a disadvantage when compared with an electromyographic device (Barreto et al., 1999). The system becomes even more interesting when we analyze the scenario where a tetraplegic user in his wheelchair and wants to make a call from his cell phone or any other task in a mobile device. The displays are way to small for any tracker and an alternative is required.

To validate electromyography as an input device we had to evaluate it in a wearable basis. Wether in Accessibility (in a wheel chair) or in Mobility issues (Walking while controlling some kind of application in a mobile device) the system is subjected to various movements. We conclude by our experiments that as long as the montage is made carefully and the wires are fixated the system acts as expected. This is a particularly lesser problem with tetraplegic users as their motor capabilities are reduced.

6   CONCLUSIONS

This paper presents EMG as a daily wearable interface. We presented a prototype where users can control computer applications through muscle contractions.

Our evaluations revealed the prototype as a fast and accurate input interface alternative. We have also shown that EMG can be used continuously even in a mobile context without unexpected behavior. This characteristic potentiates the joint use of electromyography with mobile devices in order to work in a hands-busy situation or to interact without disrupting the surrounding environment.

We have also presented a synergy between our prototype and Dasher that eases the text-entry function. This is a major contribution for users with special needs. The capability to monitorize any voluntarily contracted muscle gives us the ability to adapt the system to several impaired individuals and their special needs.

6.1   Future Work

Our work will continue with the migration of the prototype to a mobile device. We intend to continue our development in the Accessibility area, focusing on quadriplegic individuals. Our goal is to give quadriplegic the basic control of a cell phone, including messaging, with and EMG device and a mobile device attached to a wheel chair. Further user studies will be executed in that context.

We also intend to make efforts in the signal processing so we can recognize more movements with the same monitorized muscles. This will improve the interaction possibilities and number of emulated events.

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