

A WIRELESS USER-COMPUTER INTERFACE TO EXPLORE VARIOUS SOURCES OF BIOSIGNALS AND VISUAL BIOFEEDBACK FOR SEVERE MOTOR IMPAIRMENT

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Abstract: Severe speech and motor impairments caused by several neurological disorders can limit communication skills to simple yes/no replies. Variability among patients' physical and social conditions justifies the need of providing multiple sources of signals to access to Augmentative and Alternative Communication (AAC) systems. Our study presents the development of a new user-computer interface that can be controlled by the detection of various sources of biosignals. Wireless sensors are placed on the body and users learn to enhance the control of detected signals by visual biofeedback, on a switch based control approach. Experimental results in four patients with just few residual movements showed that different sensors can be placed in different body locations and detect novel communication channels, according to each person's physiological and social condition. Especially in progressive conditions, this system can be used by therapists to anticipate progression and assess new channels for communication.

Keywords: Human-computer interaction, Assistive Technologies, Augmentative and Alternative Communication, Complex Communication Needs, biosignals control, Amyotrophic Lateral Sclerosis, Locked-in Syndrome.

Introduction

Several neurological conditions, either static or progressive, can cause generalized loss of motor control and/or speech (e.g. brainstem stroke, amyotrophic lateral sclerosis, traumatic brain injuries or spinal cord lesions) (Glennen & DeCoste, D., 1996; Beukelman, Yorkston & Reichle, 2000). As modern medical care extends survival of people with marked motor disability (Laureys, Pellas & Eeckhout, 2005; Katz, Haig, Clark, & DiPaola, 1992), the impossibility to communicate has a large impact on their quality of life (Blain-Moraes S, Schaff R, Gruis KL, Huggins JE, Wren PA, 2012; Beukelman, Fager, & Nordness, 2011). Assistive technologies (AT) play an important role for enhancing or providing new communication channels to express their needs and desires, as well as to allow a more intense social contact largely beyond the very simple yes/no response. Even the most severely impaired patients can benefit from the modern Augmentative and Alternative Communication (AAC) facilities, in order to access text-to-speech and Internet tools, thus extending their communication possibilities to receive information and to participate in social networks (Light & Gulens, 2000; Nijboer, Birbaumer & Kübler, 2010; Smith & Delargy, 2005).

User interfaces to access to AAC devices are of utmost importance. Considering severe motor impairments, finding the proper sensors that fit to the user's specific physical conditions and that enable the user to efficiently generate control signals, is sometimes a difficult task. Biosignals have been explored in various ways as solutions for persons with severe motor impairments to access AAC devices and different applications. Pinheiro et al (2011) present a review on how electromyographic (EMG), electrooculographic (EOG) and electroencephalographic (EEG) signals have been extensively studied for access to AAC systems. In our study, we considered some characteristics of user interfaces based on biosignals that make these difficult to be used by users who have severe motor impairments:

- 1) Setup is complex and learning takes a long training process. Considering patients with severe neurological involvement, complexity may limit user's motivation. Moreover, the use of AAC devices is closely dependent on caregivers support, which is hard to achieve if the AT is difficult to setup and learn (Ball, Beukelman & Bardach, 2007).
- 2) No flexibility to use different sources of biosignals using the same AT system. If there is more than one choice, a proper clinical assessment can be made to study user interfaces that maximize the flow of information with the minimal physical and cognitive workload for the user (Abascal, 2008). Especially for progressive conditions, the AT should dynamically adapt to physical, physiological and psychological stages of the patients, along the course of the disease (Londral, Azevedo & Encarnação, 2009; Beukelman et al., 2000).
- 3) Many of the experimental results are obtained from non-disabled participants. Experimental studies with the involvement of the appropriate population are important. They can reveal usability factors that may be determinant for optimal design and effectiveness when applying these technologies (Clarke, Langley, Judge, Hawley, Hosking & Heron, 2011).

Aiming at avoiding the difficulties considered above, we present a new wireless control interface based on body sensors and underlying biosignals. We target patients with very few residual movements as a consequence of severe neurological conditions, either progressive or residual.

Firstly we briefly describe the proposed user computer interface, both in terms of hardware and software characteristics. We then describe the preliminary results from four patients with severe motor impairment: two women with ALS (late stage); and two men with long-standing incomplete locked-in syndrome (iLiS) (Smith & Delargy, 2005), due to brainstem stroke. We finish with a short discussion of our results.

Methodology

Design Requirements

The aim of our design was to develop a computer interface that can support the use of various sources of biosignals for accessing AAC devices.

Kintsch and DePaula (2001) have enumerated four important aspects to be considered in AT development: 1) must be customizable; 2) should be simple enough to set-up, customize and use; 3) be durable and robust 4) accommodate user's preferences, namely adapt to the users' environment and social context. Considering these aspects, we developed a new AT with the following design requirements:

- a) Support different sources of biosignals, to accommodate users' characteristics;
- b) Simple to setup and use in the daily environment of the user;
- c) Wireless and adaptable to different body movements, reducing positioning constraints and follow progressive conditions;
- d) Easy to learn (considering users and caregivers) and with minimal setup overhead.

System Description

General overview

The proposed platform was developed to enhance communication, through simple body-triggered activations. The activation (voluntarily controlled by the user) is detected using sensors placed on the body, which collect the underlying biosignals, and transmit them via Bluetooth® to the computer where they are processed in real time to detect the control activation signals (i.e user voluntary body-triggered activation). When any activation is detected, the software emulates a keystroke (e.g., to control a virtual keyboard using a scanning method) or a switch input command to an AAC software (e.g. ©TheGrid2, from Sensory Software Int). Figure 1 illustrates the block diagram of the proposed work.

Figure 1. Block diagram of the proposed system: (1) Data acquisition - user activates the sensor; (2) Signal processing - captured signal is sent via Bluetooth to the computer and processed to generate control signals; (3) Switch-based control - when an event is detected, the system sends a command to an assistive communication software (e.g a virtual keyboard)



Data Acquisition

For body signal acquisition we used a commercially available system (bioPLUX™) with 4 analog channels. This system can collect biosignals from different types of sensors and sends these signals via Bluetooth® wireless transmission to a computer (base station). Its wireless transmission range of up to 100m is appropriate for the purpose of a user computer interface. This system was setup to use a sampling rate of 1000Hz and a 12-bit resolution per channel.

Figure 2. bioPLUX system used for body signal acquisition. Sensors are connected to the system and biosignals are sent to a computer via Bluetooth.



Different sources of biosignals

In addition to wireless communication, we applied miniaturized sensors to provide comfort and flexibility. Our platform allows the application of different sensors, working as a customized solution for each user. We focused on three different body sensors, namely: a surface electromyography (sEMG) sensor (gain 1000, CMRR 110dB, 25-500Hz passing band filter, and input impedance >100MΩ), an accelerometer (ACC) (3-axial MEMS device with ±3G measurement range), and a force sensor (FSR) sensor (force sensitive resistor with 0-10Kg range and response time <5μS). Figure 3 depicts the set of sensors evaluated in the proposed system.

Figure 3. Set of sensors evaluated in our work; from left to right: electromyography sensor, accelerometry sensor, and pressure sensor.



Signal Processing

The main result for signal processing, in the proposed system, is the detection in real time, of events within the control signal. We define control signal as the processed signal that the user of the interface will voluntarily control to generate command events. After collecting the biosignal (raw data), our system processes the control signal through an algorithm to detect commands that result from the user's intention to set an activation.

Calibration. Before the user starts to control the system, there is a simple calibration process where the user is asked to stay for 5 seconds at rest position. The power of the noise signal (1) is extracted from this "signal at rest", with a calculation of the mean value for the 5 seconds (5000 samples in our case, due to the sampling rate of the system).

$$\bar{x} = \frac{1}{5000} \times \sum_{i=1}^{5000} x_i \quad (1)$$

Variance Algorithm. When a user makes a voluntary activation, the detected signal (movement, muscle contraction, or force) shows a variation in amplitude that is associated with that activation. Considering the case of sEMG signal, increased activation is correlated to greater signal amplitude. As such, the variance of an EMG signal contains important information about the voluntary activation. In our algorithm, the maximum-likelihood estimate of the local variance is computed for the windowed signal parts, in real time (Bonato, D'Alessio & Knaflitz, 1998). The maximum-likelihood estimate of the variance, which is a biased estimate, is defined as:

$$\hat{\sigma}_x^2 = \frac{1}{n} \left[\sum_{i=1}^n x_i^2 - \frac{1}{n} \left(\sum_{i=1}^n x_i \right)^2 \right] \quad (2)$$

where x_i is the magnitude of the signal in sample i and n is the number of samples defined for a data window. This function (2) is analogous to a moving average window, except for a square term, which increases the difference between voluntary activation and *no activations* (Choi & Kim, 2007). The onset of a voluntary activation is detected as the first point, which, in the variance signal, surpasses a pre-defined threshold (th) for at least an interval of 100ms (we used 100ms to ignore sporadic activations).

$$th = power(rest_signal) + N \times std(rest_signal) \quad (3)$$

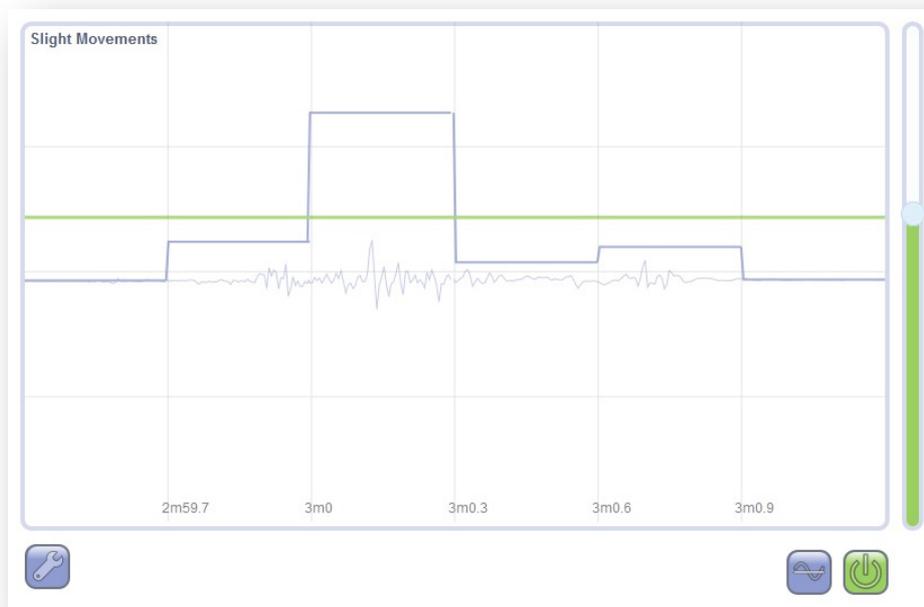
th (3) was defined as the power of the noise signal (1) plus the standard deviation error of the noise signal multiplied by a scale factor N which depends on the type of signal used.

Although a variance analysis is particularly effective to detect voluntary activations for sEMG signals, the variance analysis can also be generalized to other signals that include an activation zone. This algorithm was then used in our system for all types of studied signals (ACC, sEMG and FSR), as illustrated in Figure 4 for detection of slight movements using an accelerometer.

Biofeedback Software

The developed software platform collects data streamed in real time by the bioPLUX system through the Bluetooth® port, and shows it in the computer screen. Users can then visualize both the body signal and the processed control signal in real time, and learn how to control them using biofeedback strategies (Figures 4 and 5).

Figure 4. Visual biofeedback window developed for the presented study. Both body signal and control signal (from the variance algorithm) are visually presented to the user. User learns to control the body signal by watching it on the screen. Horizontal green line.



Customizable features

The software platform includes a customization panel. Customization is an important factor to accommodate variability among users, particularly different tasks to perform. In this panel, the user can choose which type of body action (corresponding to a specific sensor) will be performed for control, and which third-party application should receive the events generated from control signal. This is particularly important for Switch based Control (SBC) of AAC (e.g. scanning method). As an example, Figure 5 shows our system controlling an onscreen keyboard for a writing task. The variable

th (3) is also customizable, by manually changing the height of a threshold line on the screen (shown in Figure 4).

Figure 5. Example of the developed platform, controlling an onscreen keyboard to perform a writing task in a ©WordPad (from Microsoft) document. In this example, when detecting a control signal from EMG generated by the user, the key “Enter” is sent by the platform to the application of onscreen keyboard. This command performs a selection using the scanning method.



▪ Exploratory Study

With the objective of qualitatively evaluating: (1) the signal processing algorithm to detect control signals; and (2) usability issues related to sensors placement and environment adequacy, we performed an exploratory study including four participants.

Participants

The proposed system was tested in four patients with severe motor and speech impairments. All patients were between 40 and 65 years old. The selection criteria was the presence of just a few residual volitional movements, and marked difficulty to find a user interface that could fit both physical limitation and social context (considering acceptance and technical support abilities of the caregivers). Table 1 summarizes the clinical and social context of each participant.

Table 1. Selected patients included. For each participant, this table describes the place where they live, clinical condition, residual movements that were used for this study, speech preservation and the sensors tested

Participant	Residence	Clinical Condition	Residual Movement	Speech	Sensors
P1	Elderly residence	ALS	Left hand fingers and muscle contractions in the arm	Yes	ACC, FSR, sEMG
P2	Home	ALS	Right hand (closed) and head	No	ACC, FSR
P3	Long term Care clinic	Partial locked-in syndrome	Forehead muscle contractions	No	sEMG
P4	Palliative hospital service	Partial locked-in syndrome	Chin movements	No	ACC, sEMG

Procedure

Experiments were performed in a single session per participant, in their usual daily environment (see column *Residence* in Table 1), to evaluate the adequacy of the proposed system to the different environments. The purpose and procedures of the study were explained, to obtain informed consent. Furthermore, participants and caregivers were asked to give their opinion during the assessment period. They were asked to show their residual movements, and sensors were chosen according to the physical characteristics of those movements (see column *Residual Movement* in Table 1). Figure 6 illustrates a setup of an accelerometer sensor to detect slight movements of the index finger, in one of the participants of this exploratory study.

Figure 6. Detection of slight movements of index finger from the left hand in a patient with ALS.



The sensors used to assess residual movements were: accelerometer (ACC), electromyography (sEMG) and force (FSR), as described in the previous section. A computer screen was used to provide visual biofeedback of the biosignal (both raw signal from the sensor and processed control signal) to the participant, in real-time. For each setup, participants tried to execute and observe its corresponding response by visualizing biosignals on the biofeedback window (computer screen). After approximately 2 minutes watching the sensor signal and practicing simple cause-effect activities, participants were asked to fulfill two tasks, namely: T1) generate 5 to 10 onsets of the signal; and T2) generate an onset and hold it for 5 seconds. For the accelerometer sensor, task T2 was not considered. Just participant P3 had previous training sessions with a therapist, to learn how to control sEMG. Biosignals detected by the sensors during the experiments were saved for further analysis.

Outcomes were qualitative variables defined as: sources (body signals) with which users could fulfill the proposed tasks, types of sensors that the user could use to perform onsets and generate control signals and main difficulties observed in fulfilling the proposed tasks.

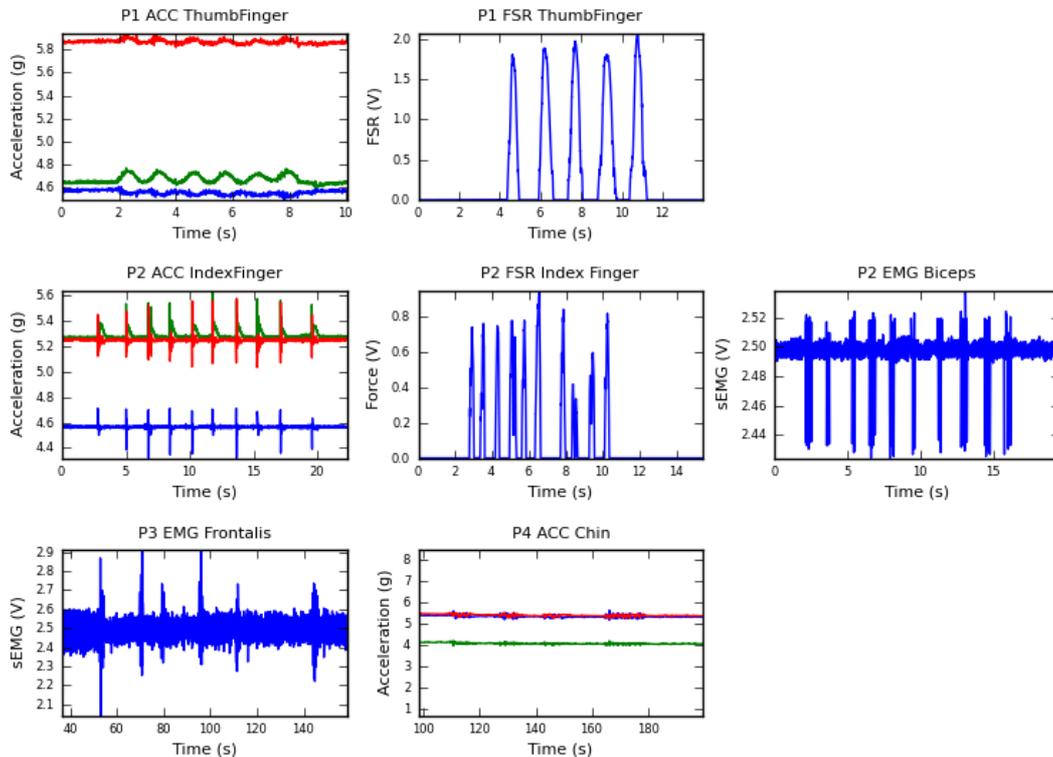
Results

All participants, except P4, were able to fulfill the first task in one body signal, at least. Table 1 shows which sensors were used to provide the control signals for each participant. P1 and P2 were able to use more than one sensor to generate control signals. Table 2 describes all the performed tasks and the characteristics for each measured control signal, showing the number of impulses detected by our system during the execution of task T1 and impulse lengths in both tasks. Figure 7 shows the biosignals corresponding to task T1.

Table 2. Characteristics of measured control signals for tasks T1 and T2

Participant	Sensor	Body placement	Task 1 Number of performed onsets / Detected activations	Task 1 Duration of control signal activations (ms)	Task 2 Onset duration (ms)
P1	FSR	Right thumb pressure	5 / 5	$\mu=839$ $\sigma=152.97$ Max=1049 Min=599	No control
P1	ACC	Right thumb movement	5 / 5	$\mu=1060.8$ $\sigma=118.1$ Max=1203 Min=856	n.a.
P2	ACC	Left index finger	10 / 10	$\mu=419$ $\sigma=112.25$ Max=599 Min=299	n.a.
P2	FSR	Left index finger	10 / 10	$\mu=404$ $\sigma=96.05$ Max=599 Min=299	5025.21
P2	sEMG	Left arm Biceps	10 / 10	$\mu=464$ $\sigma=80.78$ Max=599 Min=299	No control
P3	sEMG	Forehead Frontalis	6 / 6	$\mu=2734.6$ $\sigma=3186.62$ Max=10499 Min=998	No control
P4	ACC	Chin (inferior jaw)	5 / 0	not detected	n.a.

Figure 7. Biosignals for task T1 performed by the four participants. Titles of each plot indicate the participant, type of sensor and part of the body that actuates the sensor, as described in Table 2.



Discussion

In the described exploratory study, participants were able to perform voluntary onsets of one or more body signals, which were tested as sources of control signals. Users learned to control the movement to generate voluntary activations, using the biofeedback window. All patients were able to rapidly understand how to generate activation signals. The main difficulties in exploring different biosignals to perform the proposed tasks were the large reaction times and short awareness periods of some of the users. For participant P4, it was specially difficult to find a period of approximately 20 minutes, in which the test could be setup. Onsets were performed voluntarily by this participant (using accelerometry from chin movements), during experimental tests, though our variance algorithm could not detect them as activation signals due to their low amplitude.

One of the main positive aspects of our proposed system was the flexibility to adapt to each user context and position. Due to the wireless characteristics and use of different sensors, none of participants of the presented exploratory study had to change their environment or position to perform the proposed tasks. Moreover, we could observe that visual biofeedback is a very important tool for training control over residual movements. In our tests, this tool was used, both by the users, to learn to control the biosignal, and by the caregivers or therapists who gave feedback to the users in the learning and motivation process, in our tests.

Results from our exploratory study with four participants contribute to the implementation of design requirements defined for the development of the proposed computer interface, based on biosignals detection. In spite of the small number and difficult physical conditions of our target population, results from experimental tests with these users are important to support further developments.

Further experiments using the proposed system to perform communication tasks by access to an AAC software must be implemented. Tests will be performed on a broader range of users, exploring new algorithms for automatic activation signals detection from biosignals.

Conclusion

Patients with severe motor and speech impairments need AT to support communication. Due to patients' difficult physical conditions and strong dependence on caregivers support, ATs should be simple to setup, learn and use. We presented the development of a wireless user interface, based on the detection of biosignals and scanning access. Our system was developed to allow the use of different sensors and to detect various residual movements. Wireless connectivity and the use of sensors that are placed on the body were considered to reduce positioning constraints and open novel communication channels for those who are severely impaired. We presented an exploratory study that included four patients with severe motor impairment, in their daily care context. We evaluated biosignals from three

different sensors (ACC, FSR and sEMG) located in different body parts. From a qualitative analysis, we could observe that our interface is easy to setup and learn, and is flexible to robustly transduce residual movements from multiple sources into control signals. Biofeedback was observed as an important feature of this designed platform: participants could explore residual movements, visualize them in real time on the computer screen and learn how to control them. Particularly for progressive neuromuscular degenerative conditions, our system can be useful in the clinical assessment, to follow disease progression and search for alternative communication channels.

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