Assistive Technologies for Spinal Cord Injured Individuals: Electromyographic Mobile Accessibility

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Abstract. We present an approach for quadriplegic users to control mobile devices. Although several assistive technologies provide disabled users with computer or wheelchair control, there are still enormous interaction and control gaps to bridge: mobile device control, and subsequent communication capabilities, is one of them. An EMG-based solution is presented as well as the system's requisites, problems arisen and proposed solutions.

Keywords: Accessibility, Electromyography, Quadriplegic, Mobile Device

1 Introduction

We are used to communicate with computers through keyboards and mouse pointer devices. Although several non-conventional input modalities appeared in the last few years the traditional approaches are still overwhelming. For any physically full-capable individual there are several input modalities to choose from and it's a personal choice to use keyboards and mouse pointer devices to operate with computers. A part of the population, due to physical impairments, isn't able to choose and is often incapable of operating with electronic devices.

1.1 Spinal Cord Injury

Spinal cord injury (SCI), or myelopathy, is a disturbance of the spinal cord that results in loss of sensation and mobility. Spinal cord injuries can affect the communication between the brain and the body systems that control sensory, motor and autonomic function below the level of injury. In general, the higher in the spinal column the injury occurs, the more dysfunction a person will experience. The eight vertebrae in the neck are named cervical vertebrae. Depending on its vertebral level and severity, the individuals with tetraplegia experience a loss of motor and/or sensory functions in their head, neck, shoulders, upper chest, arms, hands and fingers. Injury between C1 and C4 is usually called high tetraplegia, while injury between C5 and C8 is called low tetraplegia. A person with low tetraplegia may still have partial motor/sensory function in his shoulder, arms, and wrists.

1.2 Context and Motivation

The limitations imposed by spinal cord injuries deprive the injured individuals from operating electronic devices like computers or mobile devices. Besides the drastic quality of life reduction directly imposed by the impairments, individuals also face a communication shutdown as they are often incapable of operating devices that make possible to communicate with others (computer, cell phone, PDA). It is a world wide concern to restitute disabled users communicative and control skills to improve their life quality. Hence, by regaining computer control disabled can through it operate any other device, easing their communication, movement and overall autonomy.
Although several assistive technologies have been developed to overcome some of the severe spinal cord injuried individuals limitations, there are still enormous gaps to bridge. To improve disabled users' interaction with personal computers and the surrounding environment the most successful approaches are based on Eye-Movement, Brain function, Residual muscle capacities, sip-puff switches or other less traditional devices like Mouth-sticks. By observing current technologies and disabled interaction we can state that the control is still limited. Although several severe impaired individuals can control a mouse pointer in a desktop PC, the usage scenario is limited and full of restrictions: when using most of the mentioned assistive technologies users have to remain steady in front of their computer. Also, we control several devices in our daily life, specially mobile devices: impaired individuals can't, even with the latest assistive technologies.

2 Assistive Technologies for Spinal Cord Injured Individuals

Assistive technologies promote greater independence for people with disabilities by enabling them to perform tasks that they were formerly unable to accomplish, or had great difficulty accomplishing, by providing enhancements to or changed methods of interacting with the technology needed to accomplish such tasks. Computer control and the subsequent electronic device or even ambient control is a actual world wide concern because it offers people with disabilities the ability to improve their life quality. For individuals with high tetraplegia, input sources for human computer interface are limited. Possible input sources include head movements, voice, eye movements, or muscles on the face. For individuals with a lower injury degree some other options can be explored accordingly to the individuals disabilities, like hand joysticks, switches or even arm muscles contraction.
Tracking approaches are used successfully by quadriplegic individuals to control the computer, whether tracking eye movement, face features or marks on the face or glasses. Face and dot marks tracking is cheaper than sophisticated eye-trackers and also more robust. All tracking approaches face the same processing flaws as well as problems with involuntary movements or voluntary movements with undesirable actions.
Another technique used to track eye movement is electrooculography, which is a technique for measuring the resting potential of the retina. It is possible to acquire,

with electrodes placed around the eyes, the electric signal generated by eye movements in both axis [1].
Brain-Computer interfaces are the most interesting when the muscular function in inhexistent (Locked-in Syndrome). In these cases, the communication channel is directly the brain, through brain wave analysis (electroencephalography). Recently, several research groups have leaned over BCI but it is still difficult to offer a real autonomous control scenario [2].
Electromyography (EMG) is a medical technique for evaluating and recording physiologic properties of muscles at rest and while contracting. This technique is also used to augment one's device control, adapting the system to the user's residual capacities [3].
There are other approaches that can somehow offer some device control: sip/puff switches, chin and hand switches, vocal joysticks, breath mouses, among others. Although suitable to some particular situations these approaches are rather limited. Furthermore, although several approaches have been presented to control personal computers, mobile device control is still very limited.

3 Electromyographic Texting

We present a system where one can control a device through muscle contractions [4]. A large set of target muscles is 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 mobile device. 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 muscle activity in an individual gives us the possibility to associate it with determined interface commands, thus having the myographic signal as input.
Although the system is usable with personal computers, we focus on mobile devices due to the lack of solutions in this area.

3.1 User and Task Analysis

In order to assess the target population capabilities and restrictions as well as the actual panorama on computer interaction we conducted questionnaires and observed six quadriplegic individuals, all male, with ages between 25 and 36. All the users present the impairment for at least four years. Three of the users have a C3-C4 lesion while the other three have a C5-C6 lesion.
Considering electronic devices, all the participants have at least one personal computer and one cell phone. All of them stated to use these devices, with some limitations. Concerning personal computers, all the users can somehow manage to interact: C5-C6 users have some arm (biceps) function and can through it (in some cases with the help of a stick atached to the hand) interact with the keyboard and the pointing device (in one of the cases emulated in the keyboard directional keys); two C3-C4 individuals interact with the computer using eye tracking devices while the

third one has an incomplete lesion and one of the arms is fully capable having no interaction restrictions except applications where two hands are needed (i.e, some computer games). It is important to notice that the interaction must occur in front of the computer and only two users stated to have this interation available while standing in the bed (with a portable PC). Furthermore, the users are transfered from/to bed at specific schedules and have limited time to operate with the computer. Even those who are capable to operate the portable PC in the bed, can only do it if they are sitted and obviously they cannot change their position without the help of another person.
The interaction with mobile devices is also limited although the devices can be always near the user. While some of the users can press the keypad (similarly to the keyboard), the others' mobile interaction is limited to atutomatically receiving calls using a bluetooth earpiece. Considering the cases where there is biceps function, the users can dial numbers and write messages (although stated to be slow), but they can only do it while they are sitted. Going back to the bed scenario, where the users are for at least 60% of the day (mean value), the interaction is minimal or inhexistent. If we consider more severe situations, with no below-neck function, mobile interaction doesn't exist.

3.2 System Goals

Observing the actual scenario on mobile interaction for quadriplegic individuals we can consider that the limitations are huge and there are several bridges to gap. The main goal of our system is to offer quadriplegic individuals the control of a mobile device, focusing on communication, calls and messages. Particularly, we intend to create mechanisms for a quadriplegic to make and receive calls and to send and receive messages. Furthermore, considering the user studies we made, these functionalities must be adapted to the users' daily life and real scenarios, whether sitting in a chair or laying down in a bed. Only by considering these scenarios we will be aiming at real accessibility.

3.2 Why Electromyography?

Our approach for mobile device control is based on myographic signal processing . Using surface electrodes it is possible to detect muscle onset and therefore associate events with pre-determined contractions or movements. An EMG-based solution is independent from ambient noise or surrounding movement in contrast to EEG and voice based approaches. Also, when compared to other physiological signals, myographic signal presents the best signal-to-noise ratio and higher amplitudes, which eases its processing and makes it a good candidate to voluntary device control. Furthermore, the number of voluntarly contracted muscles is large creating several acquistion scenarios, including cases where the impairments are enormous. The electrodes are placed accordingly to the lesion: the neck, jaw and temporal areas are presented as good choices. The independence from a display creates the possibility to use EMG in a mobility scenario. It also makes possible to interact when the users are layed down with no visual feedback, as long as alternative feedback is provided.

3.3 Electromyographic Signal Processing

In order to extract useful information from the digitalized signal we need to process it [5]. Our signal processing module is composed by a pre-processing and a smoothing phase (Figure 1).

Pre-Processing. The first stage consists in the signal amplification, A/D conversion (1000 Hz) and the application of band-pass filter (25-500Hz), removing undesired frequencies. This stage is hardware-based.

Smoothing. To detect muscle onset we need to smooth the acquired signal. To accomplish this task we centralize the samples, remove the DC offset, apply the Full-Wave rectification and finally apply a root-mean-square over the sliding window.

Onset Detection. To detect muscle activation we use a threshold estimated as a standard deviation multiple.

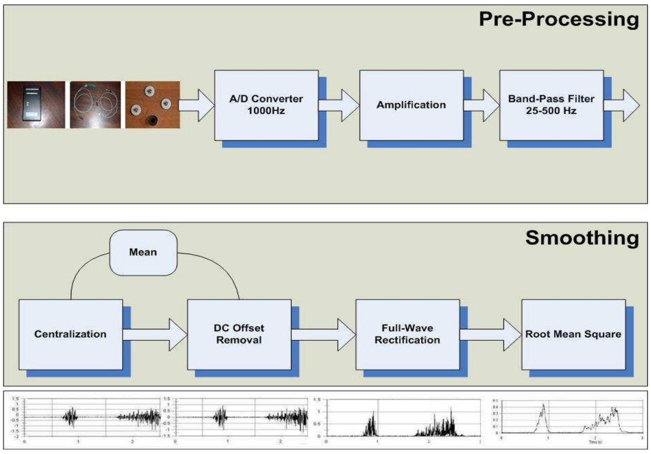

Fig. 1. Signal Processing

3.4 Use Scenarios

Our greatest concern is to create a system adapted to the users' needs and capabilities that can realy supress their mobile device interaction issues. Therefore, we have to consider the real daily life scenarios: sitting in a chair, couch or bed and laying in bed, whether turned up or to the side (Figure 2). Futhermore, we have to consider that the user isn't able to change position by himself or pick the device.

Considering these scenarios we propose two interaction modes. The first one considers visual feedback: when the user is sitted in the chair or bed he interacts with the device through muscle contractions and gets visual feedback. On the other hand, when the user is layed down he cannot see any display nor pick the device so the feedback is audio-based. The interaction bandwidth is also smaller as the movement is probably reduced when layed down.

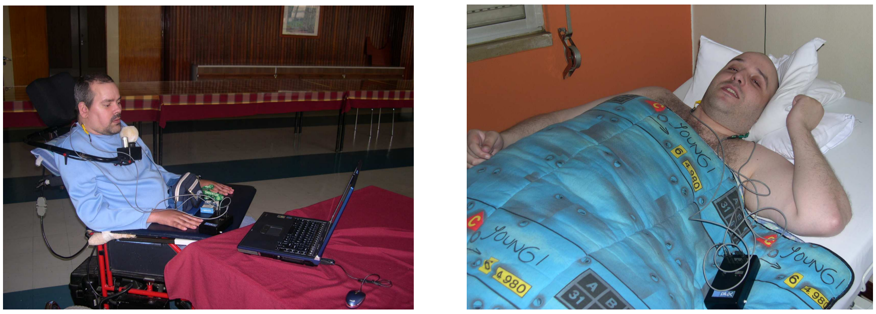

Fig. 2. Quadriplegic users in different common scenarios

The main problem in our approach is related with involuntary movements. This is even a greater problem when considering spasticity, a common collateral issue within the target population. We developed two approaches: the first one is based on the study of the movement (i.e. one can involuntarly blink both eyes but not just one; the same goes to cleenching teeth or moving shoulders up, movements that are probably volunteer). This approach suits better for scenarios where no display is available. When a display is available, the interaction is based in a dialogue: the user must follow some (more than one contraction) rules to create a certain action, decreasing the probability of undesired actions.

4 Conclusions and Future Work

We present a work-in-progress to offer quadriplegic individuals mobile device control. We have conducted user studies observing the target population real needs and capacities which showed that mobile device control is still limited or inhexistent. The future work will focus on feedback and interaction mechanisms. We will also focus on electrodes placement and fixation creating some wearable setups. We will continue to develop focusing on the users, continuously evaluating the system.

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