Biomedical Signal Processing and Control 8 (2013) 142–152

Contents lists available at SciVerse ScienceDirect

Biomedical Signal Processing and Control

journal homepage: www.elsevier.com/locate/bspc

Mouse emulation based on facial electromyogram

Adriano O. Andrade[a,*], Adriano A. Pereira[a], Carlos G. Pinheiro Jr[a], Peter J. Kyberd[b]

[a] Biomedical Engineering Laboratory, Faculty of Electrical Engineering, Federal University of Uberlândia, Campus Santa Mônica, Bloco 1E, Av. João Naves de Ávila, 2121, Uberlândia, Minas Gerais 38.408-100, Brazil
[b] Institute of Biomedical Engineering, University of New Brunswick, Fredericton, Canada

ARTICLE INFO

Article history:
Received 1 April 2012
Received in revised form 4 September 2012
Accepted 4 September 2012
Available online 25 September 2012

Keywords:
Electromyography
Facial electromyography
Human–computer interaction

ABSTRACT

This work introduces a novel human–computer interface based on electromyography (EMG). This tool allows the user to control the cursor on a computer screen through EMG activity resulting from specific facial movements. This type of human–computer interface may be useful for individuals who want to interact with computers and suffer from movement limitations of arms and hands. Although there are a number of EMG-based human–computer interfaces described in literature, most of them are not assessed with regard to the learning curve resulting from the interaction with such interfaces, being this factor one of the main contributions of the presented study. Another contribution of the investigation is the proposal and evaluation of a complete and practical solution that implements a two-channel EMG interface for generating seven distinct states which can be used as output commands. In the study, a Finite State Machine, which is the core of the system, is responsible for the conversion of features extracted from EMG signals into commands (i.e., SINGLE_CLICK, UP, DOWN, LEFT, RIGHT, ROTATE, and ON_STANDBY) used for the control of the cursor on a computer screen. The tool uses only two channels of information that combines the muscle activity of three facial muscles, i.e., the *Left* and *Right Temporalis* and the *Frontalis*. In order to evaluate learning when using the tool a customized graphical user interface was devised. This interface allowed subjects to execute pre-defined timed actions with distinct levels of difficulty. In total, 10 healthy subjects and a single subject suffering from muscular dystrophy were involved in the experiments. Approximately 60 h of practical experiments were carried out. The results suggest that just after one training session subjects could control the cursor on a computer screen, and also that incremental learning is verified over training sessions. Therefore, the devised tool may be integrated with specific programs and used by individuals whose facial muscles are not severely damaged.

1. Introduction

The familiar interfaces that have allowed humans to interact with computers have progressed significantly. In the past decade a considerable amount of effort has been devoted to the development and improvement of perceptual user interfaces (PUIs) [1]. Conversely to traditional ways of interacting with computers, which are based on typing, pointing and clicking, PUIs combine an understanding of natural human capabilities (e.g., communication, motor, cognitive and perceptual skills) and their use for interaction with computers by taking advantage of the ways in which people naturally interact with each other and with the world [1].

The use of PUIs is of particular interest in the area of rehabilitation. Patients suffering from motor or cognitive limitations can benefit from the use of this technology to ease and stimulate their interaction with the environment and especially with computers.

Currently there are a number of distinct strategies that can be used to obtain information from the user. The basic idea is to convert user inputs into commands that can be interpreted by an application [2]. The strategies can be broadly classified into the following categories with regard to the type of sensor employed in the detection of the input signal [3]: (i) press/touch (e.g., Bourhis et al. [4]), (ii) motion and gesture recognition (e.g., Javanovic and MacKenzie [5]), (iii) speech recognition (e.g., Majewski and Kacalak [6]) and (iv) biopotentials (e.g., Chin et al. [7]).

The use of facial expression recognition may not be a possible solution for patients suffering from limitations in facial muscles. In this case, the muscle contractions may be so subtle that ordinary stereoscopic cameras and infrared devices would not have resolution for detecting muscle movements. Consider, for instance, the action of teeth clenching which does not affect considerably the shape of the face but produces electromyographic (EMG) activity.

* Corresponding author. Tel.: +55 34 3239 4771.
E-mail addresses: aoandrade@yahoo.com.br, aoandrade@feelt.ufu.br (A.O. Andrade), a.alves.pereira@uol.com.br (A.A. Pereira), cgalvao@gmail.com (C.G.P. Jr), pkyberd@unb.ca (P.J. Kyberd).

1746-8094/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.bspc.2012.09.001

The main motivation for studying biopotentials is the possibility of obtaining a more natural and, conversely to on–off approaches, a proportional output [3,8].

The study of recent reviews [8–10] discussing the application of distinct biopotentials (e.g., electroencephalogram, eletromyogram, and electrooculogram) for human–computer interaction suggest that among the biopotentials the use of EMG signals is probably one of the most common and the reason for this may be related to the successful employment of EMG signals as an input for controlling prosthetic devices [11–15].

A typical application of human–computer interfaces based on EMG is for the control of augmentative and alternative communication (AAC) systems [3]. AAC systems are tools which extend the communication capabilities of individuals with impaired communication skills. An important feature that should be available in AAC systems that provide communication via computers is the possibility of controlling a cursor for the access of information on graphical user interfaces. For instance, patients suffering from neuromuscular disorders, amputees and quadriplegics can use EMG activity from muscles as input to an EMG-based interface responsible for converting such inputs into mouse actions (e.g., click) which controls an application that allows communication (e.g., writing, task selection) [16].

It is possible to find in literature a number of strategies for implementing a practical EMG-based human–computer interface with the aim of controlling a cursor on a computer screen [7,16–18]. One of the first issues any proposed system should address is the development of an experimental protocol, i.e., muscle choice and the definition of movements that will activate involved muscles.

The definition of movements responsible for muscle activation should be easy to memorize and execute, i.e., it should take into account the physical and cognitive limitations of the individual. In practice, systems which require a great amount of physical and mental effort for its operation are abandoned by the users just after a few sessions of use. For this reason solutions that require a large number of intact muscles and precise motor coordination may not be suitable for disabled individuals [19,20]. This is why most proposed systems employ a reduced number of sensors and muscles [7,16,18,21].

Although some authors (e.g., Nojd et al. [22]) have tried to establish optimal positioning of sensors for the development of an EMG human–computer interface we believe this is not a trivial problem and it should consider the physical limitations of the user and the difficulty of the movements. Facial muscles are often employed when the user has no movements from the neck down [23–25].

Typical signal processing steps involved in the classification of muscle activity into mouse actions involve signal windowing, signal detection, feature extraction and feature classification. These are common steps found in algorithms employed in myoelectric control [26,27]. All steps should be fast enough to be realized on-line, since this is a requirement of the application.

One of the most influential studies regarding mouse emulation by means of EMG signals is reported by Barreto et al. [16]. In this work the authors propose a hybrid approach, based on EMG and electroencephalographic (EEG) signals for cursor control. The level of concentration of the user is measured by means of information extracted from EEG activity that is used as a switch capable of enabling or disabling the whole interface. The mouse functions (UP, LEFT, RIGHT and CLICK) are associated with EMG activity obtained from facial movements that activates the *Right* and *Left Temporalis*, and the *Frontalis* muscles. The DOWN cursor movement is not directly linked to the detection of the contraction of any of the muscles being monitored. The indirect mechanisms used to issue the DOWN command are reported by Barreto et al. [16].

Although Barreto et al. [16] report that the operation of their system is relatively simple for the user and also that individuals can isolate left from right bite, this is not a general conclusion. In fact many individuals may experience a great difficulty in isolating left from right jaw movements, which in their approach is responsible for moving the cursor respectively to the left and right. This drawback motivated the development of a novel EMG-based interface for mouse emulation and cursor control. In addition, there is lack of studies in literature which evaluates the learning curve of users while interacting with facial EMG-based interfaces. This evaluation is an additional contribution of the work presented here.

The core of the EMG-based interface is a state machine capable of translating muscle activity from only two channels of information into one of the following states: SINGLE_CLICK, UP, DOWN, LEFT, RIGHT, ROTATE and ON_STANDBY, which are related to the state of the cursor and mouse function. The used information is facial EMG activity obtained from the contraction of the *Frontalis* muscle (when raising the eyebrows) and the difference between the muscle activity from the *Right* and *Left Temporalis* muscles (when clenching teeth).

In the next sections of the paper we describe the architecture and organization of the developed interface, together with the results obtained from practical experiments, obtained from 11 subjects (10 able-bodied and one suffering from Duchenne muscular dystrophy), focusing on the analysis of learning when using the tool over distinct training sessions.

2. Materials and methods

2.1. Description of the EMG-based human–computer interface

2.1.1. Electrode positioning and muscle activation

A pair of surface electrodes (Ag/AgCl, 2 cm × 2.5 cm) is positioned over the *Left* (E1) and *Right* (E2) *Temporalis*, and another one, which is a parallel bar (Ag/AgCl, 1 cm × 1 mm, inter-electrode distance of 1 cm) is placed on the *Frontalis* (E3).

The electrode positioning adopted in our study is shown in Fig. 1. We employed a strategy for relating facial movement with cursor control which is independent of the capacity of the user being able to isolate left from right jaw movements. This is possible because rather than using signals detected on E1 and E2 individually, we combine them (i.e., subtract via hardware) yielding, therefore, the signal X shown in Fig. 1.

An adjustable rubber band is used to maintain the electrodes fixed on the detection site. The detected signals are differentially amplified and band-pass filtered (20 Hz to 10 kHz), digitized by means of a 12-bit A/D converter, sampled at 1 kHz, yielding the signals Y (from the parallel bar electrode) and X (from the difference between the signals detected on E1 and E2). Conductive gel is used for reducing the electrode-to-skin impedance in E1 and E2, however, it is not used in E3 for avoiding short circuit between the two electrode bars.

The signal Y has EMG activity when the *Frontalis* muscle is activated, while executing actions such as raising the eyebrows. In contrast to the *Temporalis*, which moves a bone, the *Frontalis* moves the skin, which means that the actions of these muscles are completely independent one from the other.

The smaller dimension of the sensor employed in E3, compared to E1 and E2, aims to minimize crosstalk from other muscles involved in facial expression, such as the *Orbicularis oculi*. The sensor is positioned on E3 so that the left and right regions of the *Frontalis* are partially covered. This may be relevant in cases where the user has limitations in the contraction of either the left or right part of the muscle in consequence of peripheral facial paralysis.

The signal X has EMG activity whenever there is left and/or right teeth clenching. Since the *Temporalis* muscles are mostly activated during the elevation of the mandible, activities such as speaking,