Facial Electromyography as a Communication Aid and Method for Computer Interfacing (Dec. 2015)

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***Abstract*—People with motor neuron impairment or destruction, such as in quadriplegia or limb-onset amyotrophic lateral sclerosis (ALS), may have speech and dexterity difficulties, causing them to be almost completely dependent on others. Many of these people have full control of their facial muscles, which could be used as a way to help them perform certain tasks independently. In this paper we describe our use of facial electromyography (fEMG) from three sets of of muscles (the frontalis on the forehead and the zygomaticus on both sides of the face) to acquire signals for word/character selection and computer cursor control by use of recurrent signals and varying amplitudes.**

***Index Terms*—Cursor control, human–machine interface, augmentative communication, facial electromyography (fEMG).**

I. Introduction

MANY people do not have the ability to use their voice to communicate or use their hands for fine motor control. Among this population are people who suffer from quadriplegia (paralysis of the four limbs), which comprises 59% of the 12,500 annual spinal cord injuries in the United States [1], and limb-onset amyotrophic lateral sclerosis (muscle weakness and atrophy that progresses over time, starting with the limbs), with 5000 new cases annually [2]. While not all of these conditions fully eliminate use of voice to communicate or hands for fine motor control, the common factor connecting these patients is that often, these people are left with innate control of their facial muscles and have the ability to move their mouths, cheeks, eyebrows, etc.

To alleviate some of the daily difficulties these patients face, we aimed to create a method for these individuals to use facial electromyography (fEMG) for written communication and control of a computer cursor. We isolated regions of the face from which fEMG signals could be consistently and independently activated. We created a LabVIEW program to acquire fEMG and calibrated the system to the individual user's specific signaling abilities to use these signals to create written phrases, and control movement and clicks of a computer cursor.

II. Experimental Setup

Three fEMG channels each consisted of two 25 mm square self-adhesive electrodes, which were attached to the subject near the following facial muscles: (1) left zygomaticus, (2) right frontalis, (3) right zygomaticus. Each electrode pair was separated by at least 5 mm. Ends of wires were coiled to increase surface area and taped to the conducting surface of each electrode. One additional electrode connected to the ground was placed on the upper middle region of the forehead to serve as a reference signal (Fig. 1).

These three channels were then each passed into a conditioning circuit (Fig. 2), which was comprised of a differential amplifier and a bandpass filter with a total gain of 400x. The AD620 differential amplifier was configured using a 10 kΩ variable resistor R_G set to 2.60 kΩ to achieve a gain of 20x. The bandpass filter with an additional gain of 20x was constructed using an LM741 operational amplifier to achieve cutoff frequencies at f_{HP}=14.5 Hz and f_{LP}=280 Hz using R_1=50 kΩ, C_1=220 nF, R_f=1.0 MΩ, and C_f=0.56 nF. All ICs were powered by ±5.0 V DC from a DC power supply. Output from the conditioning circuits was acquired by the Data Acquisition Board at a sample rate of 10 kHz to allow further analysis by LabVIEW, which first transformed the time-amplitude signals into one standard deviation (σ) value for each data block of 1000 samples, which eliminated the DC offset (Fig. 3).

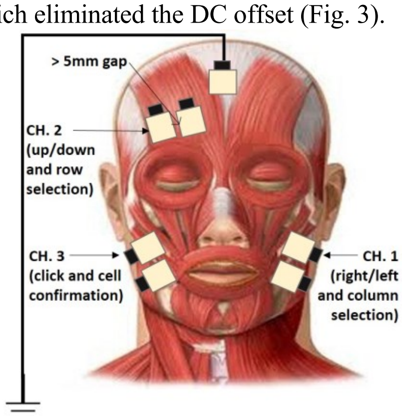


Fig. 1. Electrode configuration

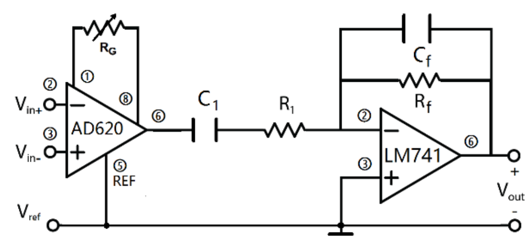


Fig. 2. The circuit diagram of a single channel of the conditioning circuit.

After connecting the subject to our system, calibrations were carried out in order to account for variations in signal strength across individuals and trials, as well as to prepare data for crosstalk analysis to confirm independence among channels of the acquired signals. To accomplish this, a dedicated LabVIEW virtual instrument (VI) prompted the subject to rest or activate each muscle for a duration of 2 s and recorded the mean of 20 σ's of each channel and muscle state, with intervals of 1 s.

In the second LabVIEW VI, i.e. the main VI, the dynamic σ values calculated in real-time from the collected fEMG signals were put through converting functions and were compared against the minimum and maximum values from the calibration to initiate the intended functions of communication and cursor control.

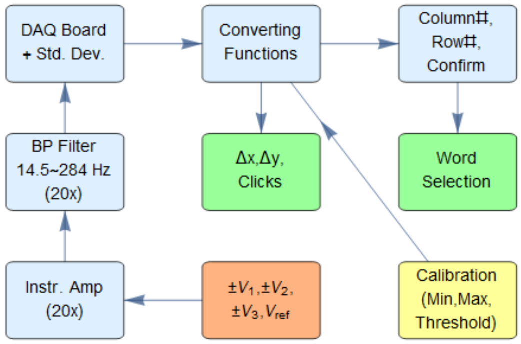


Fig. 3. Design flow diagram

To use fEMG for written communication, a table of letters or phrases was displayed to the user on the main VI front panel. To maximize user convenience, the displayed table was made to be easily customizable so that it could display words, phrases, or letters. For our purposes, we created a table of letters ordered by frequency of use in the English language to minimize the duration of fEMG activation required to select a single letter. To select a desired row, column, or to confirm the selection, the duration of the fEMG σ exceeding the threshold was compared with the trigger time to increment the corresponding counter. First, the subject used two fEMG channels to select the row and column of the intended cell. Once row and column numbers were selected, the user activated the third fEMG channel either to correct, by activating once and then correcting row/column selection, or to confirm the selection by activating the third channel twice, resulting in appending the word/character to the output array.

In order to use facial muscles to control the mouse cursor, at least 5 degrees of freedom (d.o.f.) were needed, which corresponded to upward, downward, left and right movements, and clicks. To match the required d.o.f. to the limited number of fEMG channels, we utilized a piecewise unit step function (Fig. 4), which enabled the use of one channel for horizontal movements, another for vertical movements, and the third for mouse clicks. After calibration, fine adjustments of the converting function were performed by changing two threshold levels (percentages of the difference between resting and maximally activated levels) according to the meters and lights on the front panel to ensure a free control of the cursor, the position of which was simulated simultaneously on an XY plot (Fig. 5).

Because our system was relatively tunable and reliable, the best method of evaluating this system was by looking at the speed with which a selection could be made rather than the accuracy of selection. The user was tasked to construct phrases from our keyboard table while being timed, with that time including corrections of erroneous selections.

To validate our cursor control system, we first used a defined test, the "Square Path Maneuver." The user was told to move the cursor in each direction for 10 s outlining a counter-clockwise square path, and then to initiate a mouse click once within a 10 s window. Between each movement, the user was instructed to keep the mouse stationary for 3 s. The cursor control system was also evaluated by using the AimBooster game (www.aimbooster.com). The user was required to respond to the appearance of a target on the screen by clicking on it as quickly as possible. Response times were recorded.

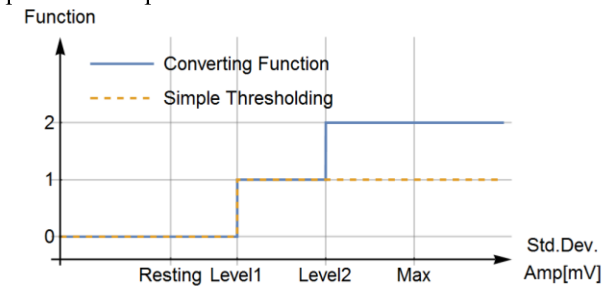


Fig. 4. The piecewise unit step converting function

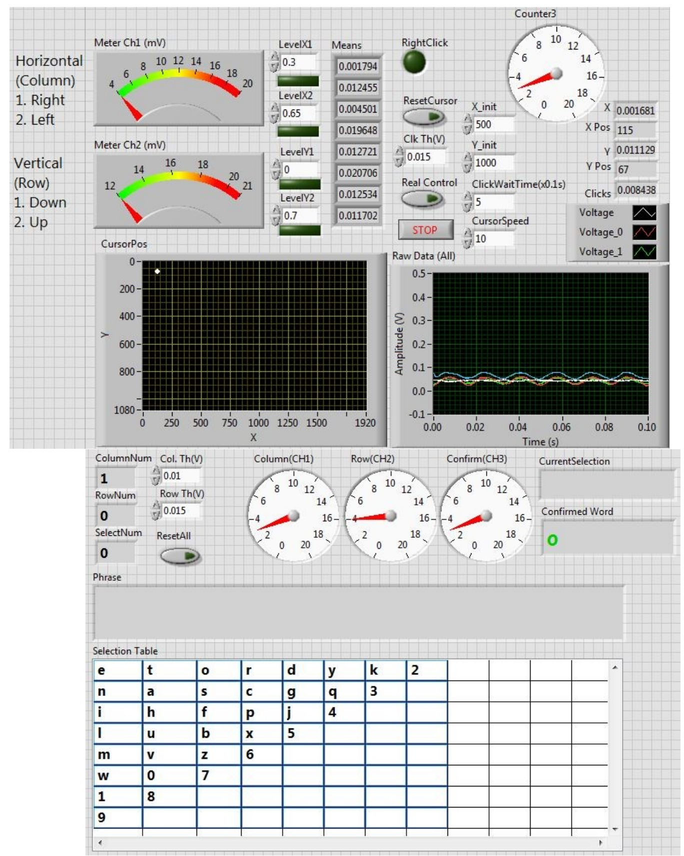
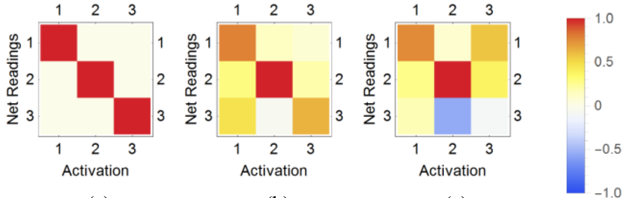


Fig. 5. LabVIEW front panel of the main VI

III. Results

From the calibration data, no significant crosstalk phenomenon was observed. Ideally, the activation of a certain muscle would only yield an increase in fEMG amplitude in the corresponding channel, i.e. the non-activated muscles should remain generating resting-level signals. After normalizing the σ values by subtracting the resting level values from the ones at the maximal effort, we plotted the results in heat maps (Fig. 6(a)). In most cases, the results were close to ideal. Bad instances (Fig. 6(c)) were often caused by hardware connection problems, which were solved immediately.



(a) (b) (c)

Fig. 6. Crosstalk analysis heat map (a. ideal, b. good sample, c. bad sample)

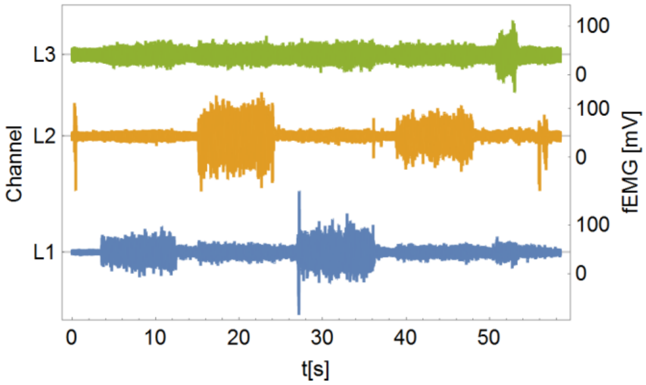


Fig. 7. Raw fEMG waveform during the Square Path Maneuver

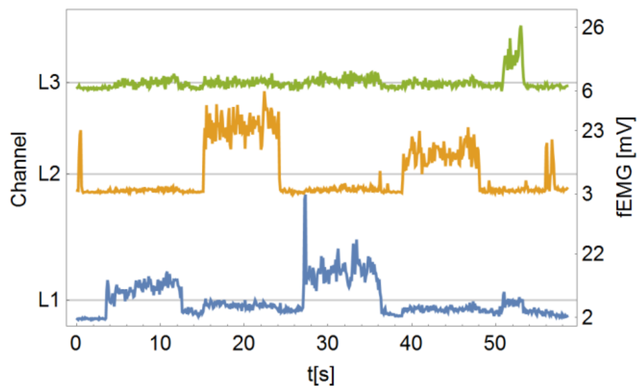


Fig. 8. Standard deviation of fEMG amplitude during the Square Path Maneuver

When the muscle was activated, the fEMG amplitude was about 100 mVpp, regardless of channel, while the resting levels greatly differed, mainly due to 60 Hz line noise, ranging from 10 mVpp to 50 mVpp (i.e. the maximum σ was about 2 to 10 times larger than the minimum) (Fig. 7). Different individuals had varying settings of threshold voltages, with level 1 values around 30% and level 2 around 70% of maximum σ (Fig. 8).

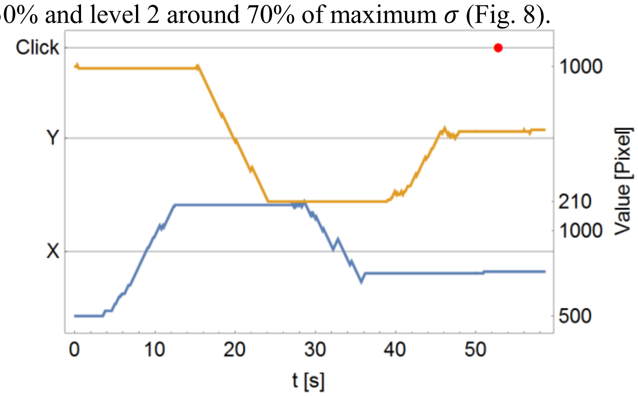


Fig. 9. Mouse position and click action as the converting function output

For the Square Path Maneuver, we used a trigger time of 0.5 s for the click function and a cursor speed of 100 pixels per second. Independence of each channel was confirmed by unidirectional movement throughout the maneuver (Fig. 9, and 10). However, the reduced overall moving distance of the cursor relative to the ideal square indicated that the converting function wasn't able to give clear results to differentiate two directions within a channel. Ability to control clicking was consistent and did not result in any unintended activation.

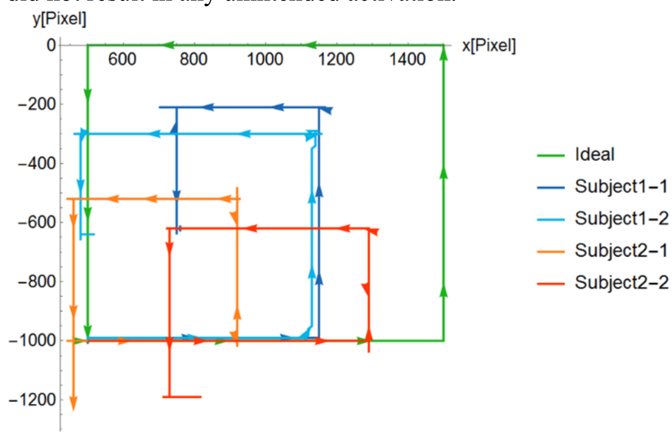


Fig. 10. Cursor path in the Square Path Maneuver (data of Subject 1-1 illustrated before)

We observed that after calibration, tuning, and some training, correct cell selection could be completed accurately and precisely. This was mainly due to the incorporation of a third channel to confirm or deny cell selection before appending to the output. The user could type the desired phrases without error with calling times per letter of 10.8 s, 11.1 s, and 8.7 s for "michigan", "iamharry", and "engineer", respectively. To give these values context, we calculated the ideal calling time (Eq. 1), which was 3.18 s per letter.

$$\begin{aligned}\text{Calling time} &= (\text{Column} + \text{Row} + \text{Confirm}) \times \text{TriggerTime} \\ &= (\text{Column} + \text{Row} + 2) \times 0.5\ \text{s} \qquad (1)\end{aligned}$$

To assess if cell location influenced calling time, the user was instructed to select cell (1,1) 3 times in a row as quickly as possible, and again for cell (3,3). This was done for 3 sets; the mean calling times were compared using an independent t-test. The mean calling times for cells (1,1) and (3,3) were 7.1±4.5 s and 6.6±0.6 s, respectively, and these values were not significantly different by an independent t-test ($p=0.711$), indicating that for this subject, these cell choices did not influence calling time.

Sensitivity of the cursor control system was determined by the number of times the cursor correctly moved predominantly in the intended direction during the 10 s window, divided by the number of attempted movements or clicks. Specificity of this system was established by noting the 3 s periods of intended non-movement, and determined by the number of non-movements divided by attempted non-movements or clicks. Across 3 users, the directionality of mouse movement and timing of clicks was very sensitive (89.6%) and specific (100%), implying that intended cursor outcome was predominant 89.6% of the time (errors were usually in the form of erroneous clicks during movement) and that when resting, the cursor did not take action. We then tested free movement of the cursor using the Aimbooster game (Fig. 11). This game gave us the ability to show how fast a user could click on targets, and we found that the mean time between clicks was 8.2±3.3 s in a field of 600 by 420 pixels with a target radius of 75 pixels.

Fig. 11. Screenshots of the AimBooster game

IV. Discussion and Conclusions

We were able to develop a non-invasive and relatively intuitive system to both communicate via written language and operate a computer cursor using fEMG. In practice, there are many components of the system which could be modified to best fit the user and the operation scenario, for instance, trigger time. A larger trigger time will minimize the click error while decrease the spatial accuracy due to possible involuntary activation of muscles of other channels. Similarly, for word selection, a larger trigger time will ensure high correct rates of column and row number input, but would extend the overall time for a single selection.

We also noticed that movement such as laughing, blinking, head turning, and speaking affected the control accuracy. To yield the best result, the subject should maintain neutral facial expression and sitting position if not activating the facial muscles for control.

Our data validation of communication aid was done using data from a single subject, a significant limitation when applying the system to the general population. We opine that, because our cursor control objective was validated with multiple subjects, and that the same channels of acquisition were used for the communication objective, our system would likely show similar typing speed results across subjects. However, further evidence would be needed to establish this. It is noteworthy that no significant difference was found for calling times between cells (1,1) and (3,3), suggesting the fEMG activation time required to call a row or column was trivial when compared to the time required to switch between row selection, column selection, and cell confirmation.

Our test subjects showed significant improvement in correct word selection rate and accuracy of mouse control after only 20 minutes of practice, where most difficulty was in memorizing the relationship between muscle location and its assigned function. We found operation to be more effective if the assignment of muscle activation to computer function followed intuition, for example, vertical movement of the cursor was assigned to furrowing of the brow, which also had a vertical movement. A design advantage of our system that we did not demonstrate was the possibility to control multiple channels simultaneously (i.e., to achieve diagonal cursor movement), which would have required more training to show.

Improvements could be made to optimize our system. Firstly, the interference of powerline noise limited the d.o.f. interpreted from a single channel. Using subtraction methods [3] in signal analysis and transferring the system to battery power are possible solutions. Additionally, electrode position was judged manually and empirically, which brought unwanted variables to the system. A helmet-like framework could be developed to increase the precision of the electrode position and decrease installation time. Different electrodes could also be used with different wire attachment mechanisms such as a snap on button for easier setup.

V. Applications

In today's society, computers are connected to almost everything - cell phones, televisions, medical equipment, etc. This system of using signals from the facial muscles to use a computer gives them the ability to perform many tasks independently. The communication component of our system could permit the user to not only have a conversation in person, but also to send emails, text messages, or simply to write. Template keyboards with predetermined words could be made for different situations so that the user would not need to type out each character of every word with an alphabet keyboard. The system could also be adapted to save personalized or frequently used words into their own template keyboard, similar to Autocorrect on cell phones. We could take our system another step further by having a voice read aloud the selected words to mimic common conversation. With regards to our cursor control component, further development could permit integration of the system with other devices, for instance, the control of a wheelchair or a prosthetic device.

Acknowledgment

The authors would like to thank the Biomedical Engineering Department of the University of Michigan, Ann Arbor for funding this project and Dr. D. Claflin, Prof. X. Fan, and Dr. B. Belmont for their technical assistance.

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