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Enhanced Hybrid Electromyogram / Eye Gaze Tracking Cursor Control System for Hands-Free Computer Interaction

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Abstract— **This paper outlines the development and initial testing of a new hybrid computer cursor control system based on Eye Gaze Tracking (EGT) and electromyogram (EMG) processing for hands-free control of the computer cursor. The ultimate goal of the system is to provide an efficient computer interaction mechanism for individuals with severe motor disabilities (or specialized operators whose hands are committed to other tasks, such as surgeons, pilots, etc.) The paper emphasizes the enhancements that have been made on different areas of the architecture, with respect to a previous prototype developed by our group, and demonstrates the performance improvement verified for some of the enhancements.**

I. INTRODUCTION

While the advent of Graphic User Interfaces (GUIs) to communicate commands to computers has simplified the cognitive demands of this kind of tasks, it has not reduced the mechanical demands of the interface. The adoption of a GUI, in fact, establishes the need for the user to exercise fine motor skills in the manipulation of input devices such as a mouse or a trackball, in order to place the screen cursor on an icon or region of interest and then execute a click command, to elicit the desired reaction from the computer's operating system.

Unfortunately, it is estimated that there are 250,000 – 400,000 individuals in the United States living with spinal cord injury or spinal dysfunction [1]. Many of these individuals lack the motor capabilities to use input devices, such as mice or trackballs, efficiently. As a consequence, they are very limited in the interaction that they can have with computers based on Graphic User Interfaces (GUIs). A similar limitation would be experienced by some specialized operators, such as a surgeon, whose hands are committed to higher-priority tasks. In view of these limitations, our group has pursued the development of a cursor control system that does not require coordinated movement of the hands, i.e., a hands-free cursor control system.

There have been a number of approaches proposed to achieve hands-free cursor control for interaction with computers. One of the most advanced approaches is the use of Eye Gaze Tracking (EGT) methods. Commercially available EGT systems are able to estimate, on a real-time basis, the point on the screen where a user is looking, i.e., the estimated "point-of-gaze" (POG). Our experimentation with this kind of systems has confirmed their reported ability to displace the cursor across long distances on the computer screen, quickly [2], [3]. However, we have also confirmed the reported inherent instability of the POG estimation and the difficulty of implementing clicking mechanisms with these systems [2], [3]. Furthermore, it has been found that the "jitter" that makes the EGT-estimated point-of-gaze unstable is rooted in the need of the human eye to perform "microsaccades", even during a fixation, to keep the light intensity reaching the dynamic retinal receptors varying (otherwise the receptors would stop providing a sustained response in the presence of a static scene) [4]. Therefore, EGT offers a great option to drive the computer cursor across large distances on the screen, quickly, but it is faced with an inherent level of noise (jitter) that makes it intrinsically inadequate when small, accurate and steady displacements are required in the operation of standard GUIs. Similarly, the difficulties of implementing "click" emulation mechanisms, by means of "dwell" or "blink" protocols have been previously documented [2], [3].

A second approach to hands-free cursor control that our group has investigated capitalizes on the availability of voluntarily-controlled electromyogram (EMG) signals from cranial muscles which the intended users of the system can still control. Electromyography is the study of muscle function through monitoring of the electrical signals generated by the muscle [5]. When a surface electrode is placed on the skin above a superficial muscle while it is contracting, it will receive electrical signals emanating from several muscle fibers associated with different motor units. The spatio-temporal summation of these electrical signals results in what is called an EMG signal. Therefore, the EMG signal provides an effective means of monitoring muscle activity. There have been previous attempts to use EMG signals for cursor control. In particular, our group has reported the results obtained with a previous cursor control system driven by EMG from cranial muscles in [6] and [7]. In our previous work, we developed a system that monitored the contraction of the right Temporalis, the left Temporalis the Frontalis or the Procerus muscles to detect when the user clenched the right side of the mandible, or clenched the left side of the mandible, or raised the eyebrows, or lowered the eyebrows. These actions were translated by the system into

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computer cursor steps in the RIGHT, LEFT, UP, and DOWN directions of the screen, respectively. In our EMG-based system, a "click" operation was commanded by simultaneous contraction of both the left and right Temporalis muscles (full jaw clench). The real-time spectral analysis on which this system was based provided a robust and stable clicking procedure and the ability to command discrete, small displacements of the cursor in any direction. However, the operation of the EMG-based system was found to be slow and potentially tiresome when large displacements of the screen cursor were required. Experimentation with this system revealed that a basic click-point-click task (select an icon located in a corner of the screen, move the cursor to the center of the screen and click on an icon placed there) took an average of 16.3 seconds, which is significantly higher than the 1 or 2 seconds required for the task with a standard mouse.

II. HYBRID EMG / EGT CURSOR CONTROL

The complementary strengths of EGT- and EMG-based cursor control systems prompted us to develop a system that combines both types of input from the user and utilizes them selectively to provide a more efficient manipulation of the screen cursor, under a wider range of circumstances. Ideally, the hybrid EMG / EGT system will use the incremental (stepping) positional commands derived from the EMG subsystem to effect small cursor displacements within a restricted neighborhood of the current cursor location. Also, only the EMG subsystem will be used to determine when the user commands a "click" operation (by the simultaneous contraction of both Temporalis muscles). In this way the cursor stability and clicking reliability observed in the evaluation of the EMG subsystem would be inherited by the hybrid system. On the other hand, when the user needs to perform a long cursor displacement on the screen, the agility of the EGT cursor control approach would be used, to reduce the time and effort required for those types of cursor manipulations.

The operation of the hybrid system described above, therefore, requires the performance of three basic tasks, in a continuous fashion:

T1) *Reliable EMG input assessment –muscular contractions must be correctly identified*

T2) *Reliable EGT fixation estimation – EGT fixations must be properly determined*

T3) *Reliable estimation of the intent of cursor manipulation by the user and resulting effective cursor update in the GUI.*

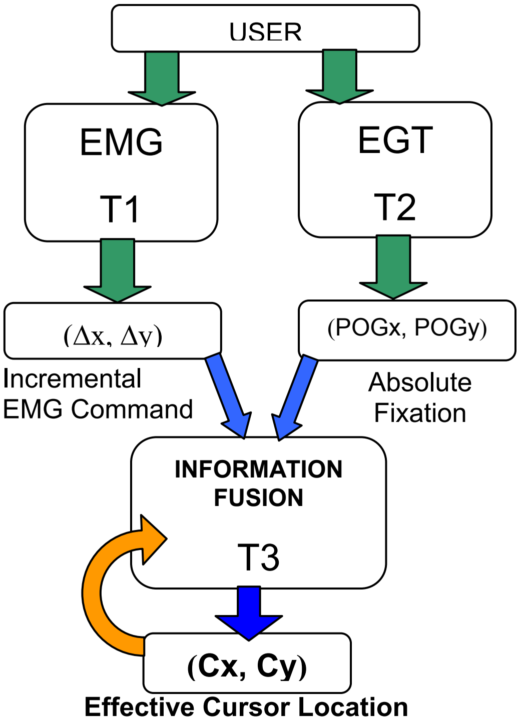

Fig. 1. Conceptual depiction of the functionality of the hybrid EMG / EGT cursor control system, on the basis of the key 3 tasks (T1, T2 and T3) defined in the text.

Figure 1 illustrates the functionality of the EMG/EGT hybrid cursor control system, in terms of these 3 basic tasks. Previously, our group developed and presented a first implementation of the hybrid EMG / EGT cursor control system that follows the concepts described in this section [8]. That initial implementation of the hybrid EMG / EGT approach demonstrated that the mean task duration for the click-point-click task referred before could be reduced from 16.3 seconds (using the EMG system alone), to 6.8 seconds (using the hybrid EMG / EGT approach). While the task time reduction observed with the hybrid system was very encouraging, further study of the performance of the three key tasks (T1, T2 and T3) in the original hybrid implementation revealed that each of them could be improved, with the aim to obtain an even better performance. This paper describes the improvements that have been implemented in each of the tasks and the initial indications we have gathered of the overall performance improvement that the enhancements will provide.

III. IMPROVEMENTS IN THE NEW HYBRID EMG / EGT CURSOR CONTROL SYSTEM

The successful manipulation of the screen cursor by means of the hybrid EMG / EGT system relies on the performance of the three tasks identified previously. The following subsections will outline the mechanisms used to achieve each goal, highlighting the ways in which those mechanisms have been improved from their initial implementation in [8].

A. *EMG Classification*

The EMG subsystem is responsible for detecting voluntary contractions of the right Temporalis (right jaw clench), left Temporalis (left jaw clench), Frontalis (eyebrows up) and Procerus (eyebrows down) muscles to command cursor steps to the right ($\Delta x = +1$), to the left ($\Delta x = -1$) , up ($\Delta y = -1$) or down ($\Delta y = +1$) respectively (screen coordinates). A simultaneous contraction of both Temporalis muscles (full jaw clench) is used to command a "click" operation.

Our original implementation used only three EMG surface electrodes, placed on the left and right temples and on the forehead of the subject, to detect the contractions of the targeted muscles. A robust detection of the contraction of a given muscle cannot be made solely on the basis of the signal amplitude at the electrode locations. Instead, real-time Power Spectral Density (PSD) estimations are performed on the EMG signals, digitized at 1200 Hz, to assess spectral features that are characteristic of each of the different muscles under observation, as a step in the process of detecting a muscle contraction. Originally, this spectral characterization was achieved by obtaining partial PSD accumulations, over specific frequency ranges, and comparing them with pre-set thresholds. The algorithm used for the original prototype was reported in [6].

A detailed analysis of the performance of the original EMG subsystem revealed that its main weakness was in detecting and differentiating contractions of the Frontalis and Procerus muscles. Therefore, we have added a fourth electrode, (in between the eyebrows) to the configuration. This new electrode is now specifically assigned to monitor EMG from the Procerus muscle, while the electrode on the forehead is now placed at a higher location to preferentially sense EMG from the Frontalis muscle (see Figure 2).

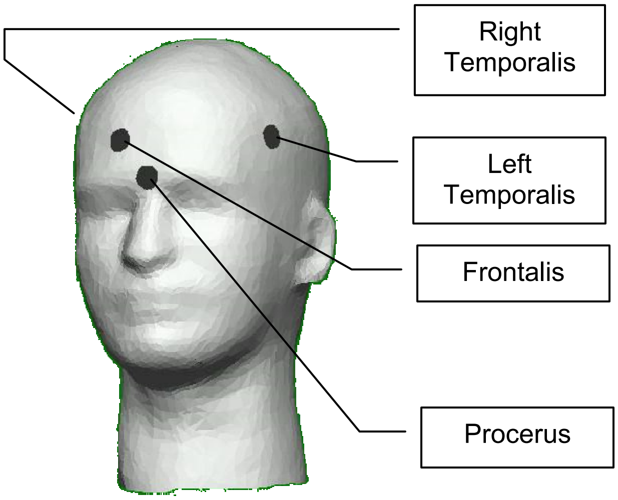

Fig. 2. Location of the EMG electrodes for the new EMG subsystem. Only the left Temporalis electrode is shown, but there is a symmetrically placed right Temporalis electrode. All EMG measurements are referenced to an electrode on the right Mastoid of the subject..

In the new EMG subsystem the characterization of spectral features of the signals is no longer made by partial PSD accumulations. Instead it is performed by locating the Mean Power Frequency (MPF) of the PSD, as shown in Equation 1 and verifying that its value appears in the range empirically defined for each type of muscle (Frontalis: 40Hz – 165Hz; Temporalis: 120Hz – 295Hz; Procerus: 60Hz – 195Hz).

$$MPF=\left(\frac{f0\times P0+...+fk\times Pk+...+fN\times PN}{P0+...+Pk+...+PN}\right),\quad k=0,1,\ldots,N-1 \qquad (1)$$

For a unilateral muscle contraction to be classified by the EMG subsystem all the following criteria must be satisfied:

(1) The maximum PSD amplitude must exceed the threshold set for that electrode.
(2) The mean power frequency calculated from the PSD must fall into a range consistent with the muscle associated with the electrode.
(3) The sum of the PSD amplitudes for the given electrode must exceed the PSD sums of the other electrodes.

For the classification of the bilateral contraction of the left and right Temporalis muscles used to trigger the "click" action, conditions (1) and (2) must be fulfilled for both Temporalis electrodes, and, in addition, each of their PSD sums must be greater than 20% of the total of both PSD sums.

In off-line tests, in which 5 subjects were instructed to execute timed sequences of the muscle contractions monitored, intermixed with rest intervals and segments of arbitrary neck movements, the new EMG classification algorithm has improved the accuracy of the classification from 78.43% to 98.42%, with respect to the old EMG classification algorithm [9].

B. *EGT Determination of Gaze Fixations*

The estimation of the point-of-gaze of the subject, in the computer screen, is performed by a commercial "eye gaze tracker". These instruments estimate the direction of the line of gaze by the relative position of the "Corneal Reflection" and the "Pupil Reflection" in an infrared image of the user's eye. The instrument calculates the coordinates of the Point-of-Gaze (POGx, POGy) in a reference plane (in this case the computer screen) by interpolation, given the location of several registration points established during a calibration process previous to the use of the EGT system [3].

Our previous EMG / EGT system used the ASL Model 5000 EGT system (Applied Science Laboratories, Bedford, MA), which provided POG coordinates at a rate of 60 / sec. In our previous algorithm these pairs of POG coordinates were used directly as contributors to the definition of the effective screen cursor updates.

In our new system we utilize the newer ASL Model R-HS P/T6 eye tracker, which is capable of providing POG estimates at higher sampling rates. Our current implementation receives POG estimates at 120 samples / sec. Further, these POG samples are no longer used directly to drive the effective screen cursor update. Instead a fixation identification algorithm is implemented to obtain a more robust characterization of the movements of the user's eye [10]. This algorithm utilizes temporal and spatial criteria to determine whether or not a fixation has occurred. More specifically, the algorithm extracts a 100ms moving window (temporal threshold) of consecutive POG data points, and calculates the standard deviation of the x- and y-coordinates of the points. If both standard deviations are less than the coordinate thresholds associated with 0.5 degrees of visual angle (spatial threshold), then it is determined that the onset of a fixation has occurred, and is characterized by the coordinates of the centroid of the POG samples received during the 100 ms window analyzed, (Fx, Fy). If it is determined that a fixation has not occurred, then the window is advanced by one data point and fixation identification is performed again.

C. Information Fusion and Effective Cursor Update

The mechanism for integrating both sources of information (EGT and EMG) towards the effective update of the screen cursor position has been revised significantly in our new system. In the previous EMG / EGT system the approach was to switch from one form of cursor control to the other. As a default the cursor position would only be adjusted incrementally according to the EMG classification results. However if testing of the POG estimates revealed that the user was driving his/her gaze far enough (as judged by a fixed distance threshold) from the previous effective cursor position, the EGT information would completely take over and the screen cursor would be re-drawn at the latest POG estimated location.

In contrast, the new EMG/EGT system always determines the effective cursor position as a superposition of the incremental EMG commands (Δx, Δy) and the absolute coordinates of a qualified EGT fixation (F'x, F'y):

$$Cx(n) = F'x(n) + \Delta x(n) \tag{2}$$

$$Cy(n) = F'y(n) + \Delta y(n) \tag{3}$$

where n is the discrete index used to described the progression of cursor updates through time.

Every new fixation centroid (Fx,Fy) identified in task T2, it is tested to determine if it is the onset of movement of the user's gaze, as a new qualified fixation (F'x, F'y). This is done by measuring the distance between the current cursor position (Cx, Cy) and (Fx, Fy). This distance is compared to a threshold defined by the Euclidean distance determined by the standard deviations in x and in y, of the POG points that resulted in the new fixation (Fx, Fy). If the distance from (Cx, Cy) to (Fx, Fy) is greater than the threshold, then (Fx, Fy) is acknowledged as representing the new position of a moving point-of-gaze, and recognized as the new qualified fixation (F'x, F'y).

IV. PERFORMANCE ENHANCEMENT

We are in the process of verifying the effective performance enhancement in the real-time operation of the hybrid cursor control system brought about by the improvements made to its different sub-sections. An initial real-time comparison involving 5 subjects verified that the implementation of the new EMG detection algorithm (alone) was able to reduce the average task time for the click-point-click task previously described (starting and ending by clicking on icons located at one corner and the center of the screen, respectively) from 16.3 seconds to 13.2 sec. It is expected that reduced task times will also be observed when the complete EMG /EGT implementation is compared to the old EMG / EGT system, which recorded an average task time of 6.8 seconds, for the same click-point-click task [8].

V. CONCLUSION

This paper has outlined the motivation and the conceptual development of a hybrid EMG / EGT computer cursor control system, for hands-free operation. The three key tasks that such a system must accomplish were analyzed. The recent development of a new EMG / EGT system was described in terms of the specific improvements that have been made in the performance of these tasks from the original system (previously documented in [8]) to the new one. Preliminary off-line and real-time results showing the positive effect of the improvements were summarized. Upcoming comparative tests involving the complete EMG / EGT system are expected to also show performance gains.

REFERENCES

[1] N.S.C.I.A. Fact Sheets: Spinal Cord Injury Statistics, National Spinal Cord Injury Association, 2005.

[2] H. Istance and P. Howarth, "Keeping an eye on your interface: The Potential for eye-based control of Graphical User Interfaces (G.U.I.'s)", Proc. of the HCI International '94, pp. 195-209.

[3] R. Jacob, "The Use of Eye Movements in Human-Computer Interaction Techniques: What you Look At is What You Get". ACM Transactions on Information Systems, V. 9 (3), pp. 152 – 169, 1991.

[4] S. Martinez-Conde, S. L. Macknik, & D. H. Hubel, (2004). "The role of fixational eye movements in visual perception". Nature reviews Neuroscience, 5, 229–240.

[5] J.V. Basmajian, and C. Deluca, Muscles Alive. Williams & Wilkins, Baltimore, 1985.

[6] A. B. Barreto, S. D. Scargle and M Adjouadi, "A Practical EMG-based Human-Computer Interface for Users with Motor Disabilities". Journal Of Rehabilitation Research And Development, 37 (1). 53-63.

[7] A. B. Barreto, S. D. Scargle and M Adjouadi, "A Real-Time Assistive Computer Interface for Users with Motor Disabilities"., ACM SIGCAPH Newsletter, 1999, 6-16.

[8] E. Lyons, A. B. Barreto and M. Adjouadi, "Development of a Hybrid Hands-off Human-Computer Interface, Based on Electromyogram Signals and Eye-Gaze Tracking," Proc. 23rd Annual International Conference of the IEEE EMBS, Vol. 2, pp. 1423 – 1426, 2001.

[9] C. Chin and A. Barreto, "Neural Control of the Computer Cursor Based on Spectral Analysis of the Electromyogram", Proc. 2nd International IEEE EMBS Conference on Neural Engineering, Arlington, VA, pp. 446 – 449, 2005.

[10] D. D. Salvucci and J. H. Goldberg, "Identifying fixations and saccades in eye-trakcing protocols". In Proc. Eye Tracking Research and Applications Symposium, FL, pp. 71 – 78, 2000.