Performance Analysis of an Integrated Eye Gaze Tracking / Electromyogram Cursor Control System

Craig A. Chin  
DSP Laboratory  
Florida International University  
Miami, FL 33174 USA  
+1 305 348 6072  
cchin006@fiu.edu

Armando Barreto  
ECE Department  
Florida International University  
Miami, FL 33174 USA  
+1 305 348 3711  
barretoa@fiu.edu

J. Gualberto Cremades  
School of Human Performance and Leisure Sciences  
Barry University  
Miami Shores, FL 33161  
+1 305 899 4846  
gcremades@mail.barry.edu

Malek Adjouadi  
ECE Department  
Florida International University  
Miami, FL 33174 USA  
+1 305 348 3019  
adjouadi@fiu.edu

ABSTRACT
Eye Gaze Tracking (EGT) systems allow individuals with motor disabilities to quickly move a screen cursor on a PC. However, there are limitations in the steadiness and the accuracy of cursor control and clicking capabilities they provide. On the other hand, a cursor control system to step the cursor up, down, left or right in response to voluntary contractions of specific facial muscles, developed by our group, provides steady and precise, albeit slow, cursor control, along with a reliable clicking mechanism. This system identifies muscle contractions by performing digital processing of the Electromyogram (EMG) signals generated by the facial muscles. Based on the complementary nature of the strengths of these two cursor control modalities we have developed an integrated EGT/EMG system in an attempt to consolidate the advantages of both input modalities. We have compared the selection accuracy and speed of an EGT-only cursor control implementation, our integrated EGT/EMG cursor control system and a standard handheld mouse in point-and click trials.

Categories and Subject Descriptors
H.5 [Information Interfaces and Presentation]:H.5.1 [Multimedia Information Systems], Evaluation; H.5.2 [Information Interfaces and Presentation]: Input devices and strategies.

General Terms
Measurement, Performance, Human Factors.

Keywords
Motor Disabilities, Cursor Control, EGT, EMG.

1. EGT AND EGT/EMG SYSTEMS
Our objective was to compare the cursor control performance achieved with an Eye Gaze Tracking (EGT) system alone, to that achieved with our integrated EGT/EMG system.

The use of EGT systems as a means of cursor control in Graphic User Interfaces (GUIs) has been studied extensively, and their shortcomings in terms of lack of screen cursor steadiness and potential for unintended selections (“Midas Touch” artifact) have been identified [1] [2]. For our study, the point of gaze (POG) screen coordinates were obtained from an ASL Model RHS P/T6 eye tracker, at a rate of 120 samples/second. A fixation identification algorithm analyzed a 100 ms moving window of consecutive POG data points, and calculated the standard deviation of their x- and y-coordinates. A fixation will be detected only when both standard deviations are less than the coordinate thresholds associated with 0.5 degrees of visual angle. The new fixation will be specified at the coordinates of the centroid of the POG samples received during the 100 ms window analyzed, (Fx, Fy). When the EGT system was considered alone, a click operation was commanded when the user’s gaze kept the same fixation for a “dwell-time” of 350 ms.

Similarly, Electromyogram (EMG) signals have been used in a number of input devices [3][4]. The EMG portion of the EGT/EMG system was driven by the analysis of EMG signals collected from electrodes placed on the right and left temples (temporalis muscles) and the forehead (right frontalis and procerus muscles). Each of these electrodes was expected to reveal the contraction of an individual muscle group, which could be used to command steps in the right, left, up and down directions, respectively. However, due to the volume conduction in the head, contraction of one muscle may cause significant EMG signals to appear in more than one electrode. Therefore, our system performs real-time spectral (Power Spectral Density) estimation and evaluates the Mean Power Frequency (MPF) from each of the EMG signals to identify which muscle contracted. The results of this spectral processing determine which stepping command should be issued, +/- Dx, or +/- Dy, if any. A click command is issued if a simultaneous contraction of both temporalis muscles (full jaw clench) is detected.

The integrated EGT/EMG updates the actual screen cursor position (Cx, Cy) using information from both EGT and EMG subsystems, according to equations (1) and (2), where (F’x, F’y) represents a “qualified fixation”, i.e., one that was detected at a distance from the previous cursor position that is larger than a pre-set threshold, and n is a discrete index [5]

\[C_x[n] = F'x[n] + \Delta x[n]\] (1)

\[C_y[n] = F'y[n] + \Delta y[n]\] (2)
2. TESTING PROTOCOLS
Two different experiments were carried out, using a 19" LCD display, at a resolution of 1280 x 1024 pixels, viewed at 75 cm (100 pixels ~ 29.4 mm). (See [6] for complete experiment details.)

2.1 Experiment 1
Three groups of ten able-bodied volunteers were formed and assigned to the cursor control methods tested: Mouse, EGT and EGT/EMG. Each participant performed 72 trials. In each trial a square “Home” icon and a circular “Target” icon appeared on the screen. The subject was instructed to click first on the “Home” icon, displace the cursor to the “Target” icon, and click in it. There were four approach directions from the “Home” to the “Target” icon (from NE, from SE, from SW, from NW), three Home-to-Target distances (286, 578 and 778 pixels), and 3 different target diameters (48, 66 and 96 pixels). Each unique combination of these factors was tested twice, in randomized order (72 trials). The movement time (“Home” click to “Target” click), and selection errors (clicks out of the icon) were recorded.

2.2 Experiment 2
Fifteen able-bodied volunteers participated in this experiment. Each performed two testing sessions with each cursor control technique: EGT and EGT/EMG. There were 32 trials in each session. Each trial displayed a green circle labeled “START” separated by a center-to-center horizontal distance of 578 pixels (13.0°) from a red target circle. The diameter of each circle was 96 pixels (2.2°). At this size, EGT-based selection errors due to accuracy limitations were not expected to be predominant. The red target circle contained a label reading either “Y” or “N”. For a given trial, the “START” circle was presented on either the left or right side of the screen, with the target circle located on the opposite side. Both circles were equidistant from the center of the screen. The trial objective was to have the user select the “START” circle and move the cursor towards the target circle. The user must then select the target only if a “Y” label was displayed within it, but not if an “N” label was displayed. If no target selection was made within 7 sec. for either kind of target, then the trial would time out.

3. ANALYSIS AND RESULTS

3.1 Results of Experiment 1
Mixed design ANOVAs were used to analyze the time and error rate results, after logarithmic transformations were applied to both the trial time [log10(X)] and error rate [log10(X + 1)] data sets, to achieve normality. The tests of between-subjects effects for trial time revealed a significant effect for cursor control technique (p < 0.0005) and the contrasts for these effects revealed that the EGT/EMG technique was significantly slower than both the mouse (p < 0.0005) and EGT (p < 0.0005) techniques. The mean +/- standard deviation time values were 0.94 +/- 0.38 sec. for the Mouse; 3.07 +/- 0.38 sec. for the EGT alone, and 4.68 +/- 0.38 sec. for the EGT/EMG. The tests of between-subjects effects for error rate also displayed a significant effect for cursor control technique (p < 0.0005), and the contrasts for these effects revealed that the EGT/EMG technique had a significantly smaller error rate than the EGT technique (p < 0.0005). The contrasts also showed that the error rate produced by the EGT/EMG technique was comparable to that of the mouse (p = 0.206). The mean +/- standard deviation error values (in errors/trial) were 0.01 +/- 0.24 for the Mouse; 0.13 +/- 0.24 for the EGT/EMG and 3.98 +/- 0.24, for the EGT alone.

3.2 Results of Experiment 2
Experiment 2 was treated as a repeated measures experiment. The number of selections of “N” label targets (selection errors) per session was studied. Since the data were not normal, non-parametric tests (Friedman test and Wilcoxon signed-rank test) were used. The mean error rates (per trial) were 0.396 for the EGT system and 0.017 for the EGT/EMG system. The Friedman test revealed that the difference between the ranks of each treatment condition was significant (p < 0.0005). The Wilcoxon test indicated that these differences were due to effects of the cursor control techniques, because significant differences were only found between treatments that involved different techniques.

4. CONCLUSION
The experimental results indicate that the integrated EGT/EMG cursor control system was somewhat slower than the EGT system alone, but also indicated that EGT/EMG provides increased precision and more reliable left-click over EGT, as evidenced by a significantly lower error rate. The enhanced accuracy achieved with the inclusion of EMG control may reduce the frustration sometimes experienced by EGT interface users. It is also feasible that more extensive periods of EGT/EMG interface usage may help subjects become accustomed to its dual-mode nature and may result in additional speed gains. Future tests involving individuals with motor disabilities will illuminate these questions.

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6. REFERENCES