EOG signal processing and analysis for controlling computer by eye movements

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ABSTRACT

We have successfully designed and built a human computer interface system to interface with the computer by human eye EOG signal (Electrooculography). The EOG signal has very low voltage and very sensitive to interference. This paper introduces the software we developed for processing the EOG signal which lead to a reliable human computer interface by eye movements.

Categories and Subject Descriptors
H.5.2 [User Interfaces] *User-centered design*

General Terms
Software, Measurement, Design, Experimentation, Human Factors

Keywords
Human-Computer Interaction, EOG (Electrooculography), eye movement tracking

1. INTRODUCTION
There is no magic now to control a machine by pushing a button by a finger. Human-machine interaction has never been so easy. Are there even easier way to control a machine without even pushing a button? Our answer is yes. For example, one can control a machine by only looking at it. As the advance of computer technology, to control any machinery that is equipped with a computer has become a common fact. The lacking element of controlling a machine by eyes becomes how to control a computer by eyes. Many studies have been done towards this goal such as [5][6][8][9][10], among others.

Towards this goal, we have studied the characteristics of the EOG signal and its possibility to be an accurate human machine interface. We successfully built an experimental system that can study the bio-physiological signal to control the computer only by eye movements [1]. The system recorded the EOG signal[2][3][4] from user eye movement and positions the cursor on the monitor to control the computer as a normal cursor does. See Figure 1 of the system modules. For the novelty of the system, please refer to [1] for more details.

In this paper, we will introduce a key element in the system which is the software subsystem for the experiments on the EOG signal. It serves for the processing and analysis of the signal for cursor position control. This is the base for the software module in Figure 1. The development has two stages. The first stage is the development of the software subsystem for the experiments. The second stage is a modification on this experimental subsystem to form the software module in the global system. Important technical issues in this subsystem will be presented with testing results.

The software subsystem will be presented first. The subsequent sections will describe its elements one by one.

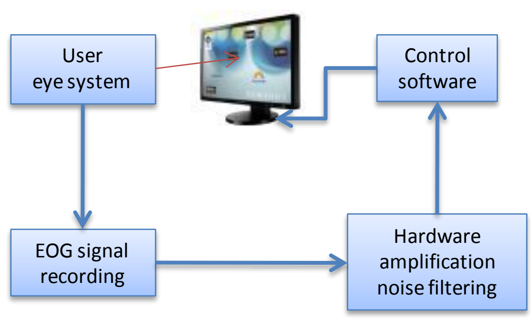

Figure 1. Cursor positioning by EOG signal

2. THE EXPERIMENTAL SUBSYSTEM
The objective of building the software subsystem in the experimental user interface is to use an inverse engineering approach to generate ideal cursor movement patterns for the user eyes to follow. The EOG signal from the user eye movement following these patterns are recorded and compared with ideal signals. These helped us to identify all the important issues in building the final software module to control the cursor by eyes.

The basic functions of the software subsystem are designed according to the need of the experiments. The basic functions are: configuration of the system parameters, recording the detected EOG signal, comparison of the recorded signal and the perfect produced signals, and to process the signal. The components of the software subsystem for the experimental system can be seen in the Figure 2.

2.1 THE CONFIGURATION MODULE

The configuration module is for configure all the equipments in the system such as the digitalization card for signal acquisition and the signal visualization, the filtering parameters, the creation of file folders for the recorded EOG signals.

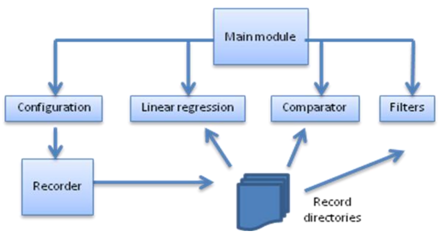

Figure 2. Components of the experimental software subsystem.

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2.2 THE RECORDING MODULE

This module is in charge of generating the experimental stimuli signals and recording the EOG signal from the user eyes. It will record both generated standard signals and the signals from the user eyes. The basic algorithm of this module can be seen in the following:

```
begin
        Exit: = false;
        Read (Exit);
        while Exit = false do
        begin
                Read parameters of the experiment;
                Configure acquisition parameters;
                Open log file for record;
                Generate point matrix of cursor movement;
                Move cursor to start position;
                Initialize audio signal;
                Wait time of initiation;
                While there are cursor movement points do
                begin
                     Move cursor to next position;
                     Wait for the next multiple of the ISI;
                     Get time;
                     Read EOG signal;
                     Save time, cursor position and EOG in
                     matrix;
                End;
                Compute statistics;
                Save record file;
        Close record file;
End;
     Read(Exit);
End;
```

The first part of the algorithm is for setting all the experimental configuration parameters such as: generated movement pattern, time between each cursor movement (***ISI***: *InterStimuli Interval*), iteration time, lateral margin, number of generated cursor movement points.

The second step is to configure the digitalization card. The matrix of cursor movement points is generated according to the test pattern, number of points selected along x direction. Along with the ISI and the monitor size the cursor movement velocity can be decided.

The experiment begins with the cursor in the initial position. An audio signal will be generated as well to inform the user that the generation of test pattern will begin. The user can then follow the test pattern by eye movement.

We calculate the statistics during the EOG signal recording. We calculate the arithmetic mean, standard deviation and the maximum and minimum values of ISI. These values provide the information needed to validate the recording. The algorithm ends with the saving and closing of the record file.

2.3 THE COMPARATOR MODULE

This module is for comparing the recorded signal with the respective generated movement pattern to establish the scaling and offset factors to adjust the signal on both dimensions. We apply a parameterizable moving average smoothing filter to the signal to better visualizing it. It is also possible to measure the differences between the levels of different points to determine the drift value in a specific time interval.

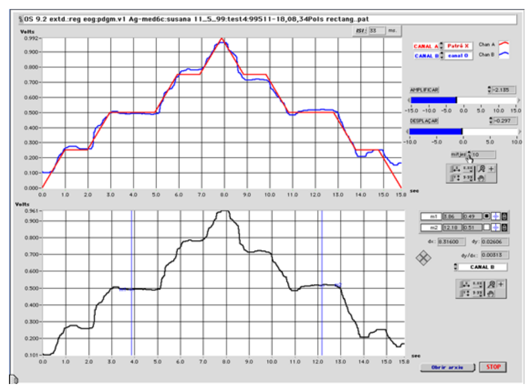

Figure 3. The comparator module

In Figure 3, you can see the result of comparing the x component of a generated cursor movement pattern with the EOG signal. The EOG signal has been applied a scaling factor of -2.135, and a displacement of -0.297, and a median filter over a window of 21 points.

2.4 THE FILTER MODULE

One of the tasks, in addition to comparing the EOG signals with the generated one, is to have a simple method for the detection of voluntary and involuntary eye blinks in the EOG signals. The filtering module is for adjusting the frequency of a high-pass filter to isolate the blinking. It is also used for adjusting the low-pass filters frequencies.

The module starts by selecting a record file and the filter type. Then it selects the cutoff frequency and calculates the result of applying the filter on the EOG signal. As shown in Figure 4, the right part is the original EOG signal and the left part is the result of applying the high-pass filter with cutoff frequency at 8 Hz. In the first and third channel on the left one can see the pulse signal corresponding to the eye blinking.

2.5 THE LINEAR REGRESSION MODULE

The purpose of this module is to approximate the user's eye position from the EOG signals of one or more record files using the cursor movement patterns. It is assumed that the user pursuits the foveal cursor movement during recording without moving the head.

Before processing the signal files, it is possible to apply a moving average filter to smooth the EOG signals. The module also allows the calculation on a selected range of the signal.

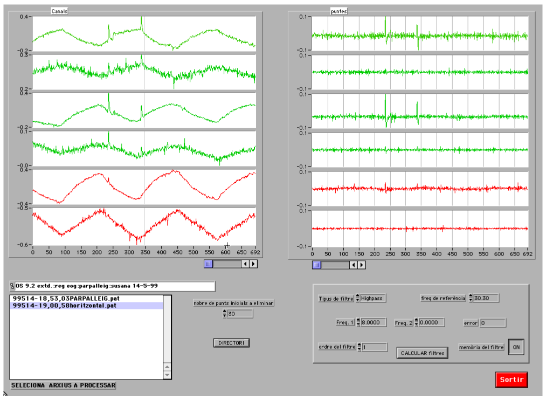

Figure 4. The result after the filter module

The filter generates a new sequence of points from each channel of EOG input by calculating the arithmetic mean over a window of length specified by the parameter range. If x_i is the value of the filtered signal at time moment i, m the number of samples of the signal and r is the value range, the effect of filtering for each sample can be expressed as:

$$F(i) = \frac{1}{2r+1}\sum_{i-r}^{i+r} x_j \ ; \ 0 \le r \le m. \qquad i = 1, 2, \ldots, m.$$

After performing this operation for each channel of the recorded signal it is ready for a linear approximation of the signal.

To make the linear approximation, two systems of linear equations are used with the eye movement patterns and eye EOG signal records as follows:

$$P_x(i) = a_0 + a_1C_1(i) + \ldots + a_{n-1}C_{n-1}(i) + a_nC_n(i); \quad i = 1, 2, \ldots, m.$$

and

$$P_y(i) = b_0 + b_1C_1(i) + \ldots + b_{n-1}C_{n-1}(i) + b_nC_n(i); \quad i = 1, 2, \ldots, m.$$

where P_x is the horizontal component of the cursor movement pattern, the P_y is the vertical component. C_i are recorded EOG channel signals, the coefficient a_i is for the horizontal component, and b_i for the vertical component. n is the number of record channels, and m is the number of samples in the interval to be treated.

In each system of equations, the coefficients are calculated using the method of least squares. Once the coefficients of each system are calculated, function $F_x(i)$ and $F_y(i)$ will be used for reconstruction of each component of eye movement signal. We choose the mean square error (mse) to calculate each component:

$$mse_x = \frac{1}{m}\sum_{i=1}^{m} (F_x(i) - P_x(i))^2 ;$$

and

$$mse_y = \frac{1}{m}\sum_{i=1}^{m} (F_y(i) - P_y(i))^2 .$$

Figure 5 shows some results of the linear regression module. The selected file is highlighted in the bottom left. The pattern of movement is cosinusoidal. The file contains 6 channels of recorded signals. The lower two correspond to the x component, the remaining four correspond to the component *y*. To smooth the signals a filter has been applied with r = 5. The sample interval is 6 seconds.

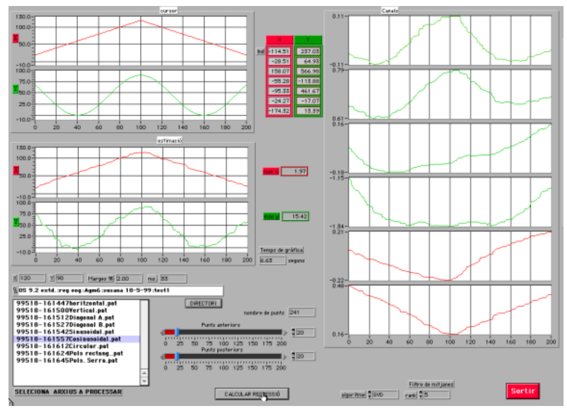

Figure 5. The linear regression module

3. THE SOFTWARE IN THE FINAL SYSTEM

With the above experimental software subsystem built, we have identified a series of key factors that are vital to build the final software subsystem. They are the linearity range of the EOG signal, the users' foveal pursuit movements, the interference in the EOG signal that can seriously affect the cursor control such as drift, high frequency noise and the eye blinking etc. Based on large number of experiments and many iterations of problem finding – problem solving, a final version of the software subsystem is built as described in [1].

The major modules in the final subsystem (Figure 6) are the Main module, the Acquisition, synchronization module, Cursor position calculation module and the Cursor movement module. The algorithm for the main module is as the follows:

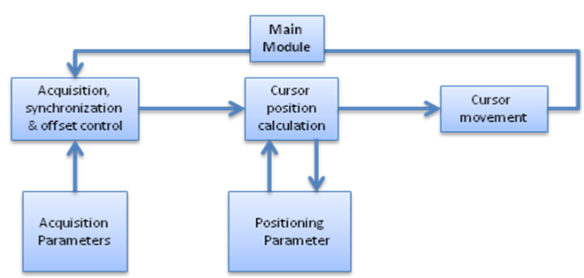

Figure 6. The software subsystem for EOG signal processing

```
Begin
    Initialize global variables;
    Set digital output;
    Read (Exit);
    while Exit = false do
    Begin
        Read (Start);
        Read (movement activated);
        If Start = True then
          Begin
            Read (settings);
            Setting acquisition;
            Set initial offset;
            Stop: = false;
            While stop = false do
                Begin
                  Acquisition and offset control;
                  Draw graphics;
                  Put signal into buffer;
                  If movement activated
                    Begin
                        Calculate the cursor position;
                        Update cursor position;
                    End;
                  Read (Stop);
                End;
          End;
          Read (Exit);
    End;
End;
```

In the algorithm, the logical variable Start controls the beginning of acquisition of EOG signal samples and the variable Stop interrupting the acquisition. This enables the guiding of eye movements with different values of the parameters of acquisition. The variable is used for movement on and off control of eye movement signal, so you can activate the acquisition of samples of the EOG signals and display signals without activating the control of eye movements.

When the process starts to monitor the eye movement, with movement activated = true, the main module executes the sequence of instructions from the central loop which consists of a succession of calls to the various modules that are part of the system. For more information about the functions of other modules and evaluation results, please refer to our paper [1].

4. RESULTS

We used the screen resolution 1024x768 and 800x600 in our system evaluation.

The resulted control accuracy can reach 8 pixels at the resolution of 1024 x 768 and 4 pixels for a screen resolution of 800 x 600 pixels. The system successfully interacts with a set of applications on the screen.

5. CONCLUSIONS

The software subsystem has fulfilled its role in the global system for using eye movement to control a computer. It controls all the stages of the user-computer interface from the EOG signal acquisition, sampling, buffering, processing and forming a signal to move the cursor on the screen. All the programs that can be controlled by cursor movement are then controlled by the user eyes. There are some vital problems that the hardware cannot solve such as high frequency interference and signal drifting. It is the software that provides solutions for them.

6. ACKNOWLEDGEMENTS

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