# Low Cost Human Computer Interface voluntary eye movement as communication system for disabled people with limited movements.

Vazquez L. J. G.[1], Minor M. A.[1], Sossa A. J.H.[2]
[1]CINVESTAV-IPN, Mexico D.F., Mexico
[2]CIC-IPN, Mexico D.F., Mexico
Email: jgvazquez@cinvestav.mx; Ph. (55) 5747-3800

*Abstract* — **The ability to identify the location of human pupil offers us the possibility to know the eye gaze target of a person. This infers the possibility to create new methods of human-machine interaction. Nevertheless there are some barriers and restrictions that are shown in the integrations, as intrusion, robustness, availability and price of the eye track systems.**

**This paper describes the develop and usability of an eye gaze input system using a web cam with infrared LEDs over a head mounting system.**

**Most available eye gazing with head mounting have two characteristic that hinder being widely used as human computer interfaces. The first is represented by the need of a calibration stage before the use; the second is about the low tolerance for head movements during all the using time. This work solved that problem using a 3 axis accelerometer as head tilt sensor to make a compensation.**

**Our main objective is to create a communication system for people with motor disabilities based exclusively in self-inflicted ocular movement.**

*Keywords* — **eye gaze tracking, gaze estimation, head tilt sensor, human-computer interface**

## I. INTRODUCTION

Several input devices using voice, gaze and head or tongue movements have been developed for human-computer interfaces[1,2,3,4,6,7,12,13,14], all of them attending the need of interaction in the world of disabled people. The new technology allows to made the measurement of eye movements easier, faster and more accurate. Due to this a lot of systems had been developed, increasing the work in this area.

Clearly the input properties of the eye gazing input system show a disadvantage respect to the standard mouse, in comfort and execution time nevertheless the possibility to bring an alternate system of communication for disabled people makes an incentive to upgrade all this work.

The eye gazing input systems had been available for over 40 years, some manufacturers are ASL, LC, I-Scan, usually those systems use Purkinje image and Limbus tracking technology, with head movement compensation given by a face image.

Due to possibilities, tracking eyes motion in real time is not a new idea . The most common method involves finding the centre of the pupil with respect to a Purkinje image[1,3,4,6,7,12,13]. From these two coordinates a distance can be easily measured. However to achieve correctly those two coordinates the ambient illumination must be carefully controlled. In the other hand infra-red light source is advantageous in pupil tracking, as it causes strong gradients in image intensities along the pupil. It also provides less dependency on surrounding lighting, making it a preferred method.

Creating a system to control the cursor of a computer requires not only to obtain the center pupil coordinates, also requires a calibration stage to create a set of positions of the eye gaze according the coordinates. Including a methodology to execute commands.

In this case voluntary eye blink had been chosen as the trigger for actions as it has a longer duration respect to the involuntary eye blink with an average time of 0.03 seconds.

Taking in consideration that the natural head movements represent an error factor in the eye gazing estimation, this work propose the use of accelerometer to recalculate new coordinates based in the head tilt.

As the main objective of this work is to create a communication system for people with motor disabilities, it had been included graphic user interfaces that allows the user to answer affirmative/negative questions, write in a virtual keyboard and declare pain points over a human figure including intensity.

## II. METHODOLOGY

### A. Head Mounting System

The head mounting system had been designed based on ergonomics, lightweight, low cost, and an anthropometric study[10] having the capacity to integrate a web cam and a tilt sensor. Figure 1 shows the head gear system in CAD and Figure 2 shows the developed eye tracking device. To reduce user's burden the system uses a web cam with infrared LEDs to have lightweight and small size. The head gear is designed to measure wide area equivalent to one's eye sight.

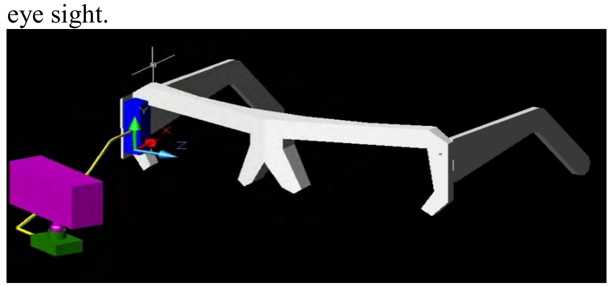

Fig. 1 3D-CAD model for a headgear

Fig. 2 Headgear mounted

B. Image Processing of Eye Tracking Camera Image.

Most eye tracking systems developed as practical application use a technique called Purkinje image tracking.
When a point source of light is reflected into the eye, the image obtained is called the Purkinje image. The relationship between the pupil center and the center of the Purkinje image can be used to determine eye-gaze angle. Purkinje images, however, fail if the reflection does not fall on the spherical part of the cornea. And the images do not appear when the eye moves widely from the center location. Due to this at the present work, we had chosen to use a 'dark pupil method'. This method uses pupil's dark area in the eye to track in the camera image.
We expect that the eye image is processed by the dark pupil method to find the pupil center in wide area and with high speed.

Using environment light is hard to find dark pupil area so an infrared light source is a good option to illuminate the wide eye area, allowing to obtain images without luminance variability. Infrared LEDs were used in pupil detection to create a high intensity bright spot that is easy to find with image processing. This bright spot occurs when infrared is reflected off the back of the pupil and magnified by the web cam lens.

B.1 Algorithm to detect pupil's center

The image obtained with the web cam using the infrared LEDs shows high contrast and eliminate almost all the undesired regions, nevertheless there are a variety of factors involved that might cause damage to the eye due to excessive infrared absorption.
Factors include time, wavelength, power and the absorption rates of tissues. The power or luminescence is the major safety consideration.
Infrared A light of 400 to 1400 nanometers is magnified in the eye by the cornea and lens and can increase irradiance up to 100,000 times on the retina. This can be problematic as the eye can only see up to approximately 700nm and any excessive light above this period could be a risk factor. The magnified light is converted to heat within the eye and can potentially cause cataracts and retinal or corneal burns[9].
However, these are unlikely as long as the source power is sufficiently low. Using the radiant power, the radiance can be derived using the area of the LEDs:

$$radiance = \frac{radiantpower}{area} = \frac{radiantpower}{2\pi R^2}$$
$$radiance = \frac{130\frac{mW}{sr}}{(0.001\mathrm{m})^2\pi} = 4.1x10^4\,\frac{W}{m^2xsr} \quad (1)$$

the equation (1) shows that the use of this light is safe for the user according international standards[8].

The figure 3 shows the image obtained, due to the characteristics of high contrast and low noise, and searching a faster method to obtain the pupil's center had been chosen the lateral histogram as the kernel of the algorithm. Using this equation

$$position_x = Arg(Max(lateralhist_x(image)))$$
$$position_y = Arg(Max(lateralhist_y(image))) \quad (2)$$

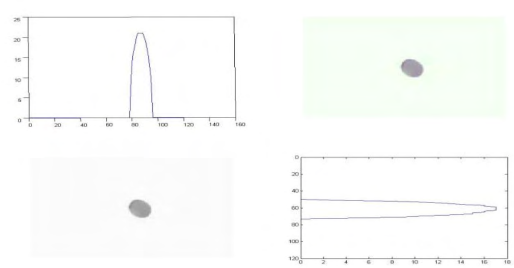

Fig. 3 Image obtained and lateral histograms

B.2 Thresholding and binary image

The classical approach to find a good threshold begins by making an assumption regarding the minimum and maximum area for the pupil in the image. Then it construct an image brightness histogram and search (starting from the bin containing the darkest pixels) for the first bin where (a) the cumulative sum is greater than the minimum area and (b) the cumulative sum is greater than the maximum area. The threshold τc is chosen to lay between these two bins . In this case this classic method not always represent the best threshold value for our interest, because the eyelash in some cases are not eliminated and represent a error factor. To reduce this problem, this work propose a re-thresholding based in the first frames during the calibration stage.

The method consist in calculate the classical thresholding before described, after that find component connected areas and count all the objects, if the sum of the objects is more than one, then upper the threshold level 1% and find again the number of objects until just one object is left after the component connected area.


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C. Classification and command interpretation

This section describes the methodology to classify the coordinates of the eye gazing and based in the results generate an activation model to execute actions for the computer's cursor.

C.1 Calibration stage

The Calibration Process allows the number finding program to be able to reference the pupil center's respect some specific points in the screen. All points must be calibrated before the program loop will run. The calibration process takes some image snapshot and records the x,y coordinates of pupil's center. Using mean, variance and standard deviation of all the data, the calibration algorithm generates a set of inputs and outputs data that will pass to an artificial neural network

For the user, calibration stage consist in keep looking a target on the screen during a few seconds until the next target appears over the screen, as it is already mentioned in this stage also it is find the best thresholding value to make it binary.

C.2 Neural Network

Even the data set for inputs are linearly separable and a simple algorithm to find the boundaries between different class could be used, it had been chosen a Perceptron Multilayer Network as pattern recognition network using feed-forward by mean square error for training as it has the capacity of create a model with low gradients at the output function.

After trying some configurations for the neural network, a perceptron multilayer network with 20 neurons at the input layer, 15 neurons in the hidden layer and 2 neurons at the output layer, shows good performance for this issue.

C.3 Command interpretation

The neural network output is interpreted as new coordinates for the cursor, through JAVA© methods this system set the cursor proprieties in the operative system (Windows).

The users just need to look at least 300 milliseconds to the interest point in the screen to move the cursor in this direction. Once the user locates the cursor in the screen , the user only need to blink and the system will execute the click action.

Clearly this system need a command to return control for a natural mouse. This occurs when the user closes his eyes at least 5 seconds.

D. Head Tilt estimation

Accelerometers can be used for measuring both dynamic and static measurements of acceleration. Tilt is a static measurement where gravity is the acceleration being measured. Therefore, to achieve the highest degree resolution of a tilt measurement, a low-g, high-sensitivity accelerometer is required.

In this work the use of the LIS 3L02AS4 represents a device with low-power three axes linear accelerometer that includes a sensing element and an IC interface able to take the information from the sensing element and to provide an analog signal to the external world . According the data-sheet[] to determinate a tilt angle:

$$\theta = \arcsin\left(\frac{V_{out}-V_{offset}}{\frac{\Delta V}{\Delta g}}\right)(3)$$

where

$$\theta = tiltangle$$
$$V_{out} = accelerometervoltage(Volts)$$
$$V_{offset} = compensationvoltage(0\text{g})$$
$$\frac{\Delta V}{\Delta g} = sensitivity.$$

The Communication between PC and sensor is through the RS-232 protocol using a PIC18fXX as ADC and driver protocol.

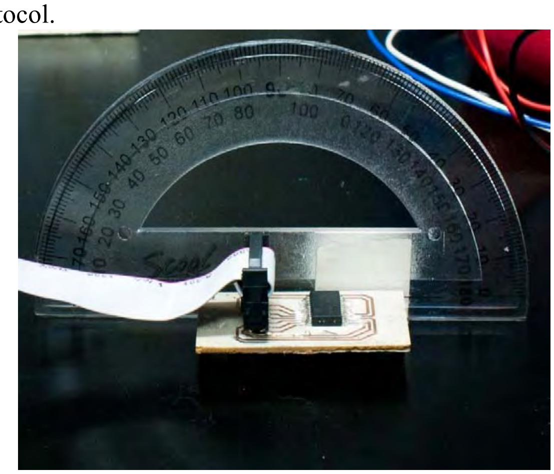

Fig. 4 IS 3L02AS4 device

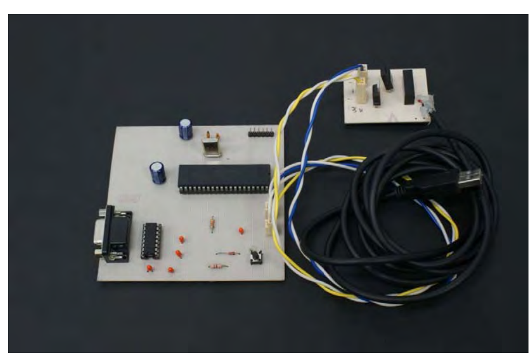

Fig. 5 RS-323 converter for IS 3L02AS4


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During the calibration stage the user can't move his head, once the systems is calibrated, the user is allowed to tilt the head in any direction .

The system compensate the coordinates of the eye gaze based in:

$$X_c = L\sin(\tan^{-1}(\frac{\frac{d_0}{d_c}(d_f - d_c)}{d_f}) - \tan^{-1}(\theta))(4)$$

where

$$L = neck, eyedistance(m)$$
$$d_0 = eye, camdistance(m)$$
$$d_f = eye, screendistance(m)$$
$$d_c = neck, screencenterdistance(m)$$

E. Graphical User Interface

Generally graphical User Interface refers to an user window in the screen where the click action execute commands and the result of those commands are presented in the same screen.

Designing the visual composition and temporal behavior of GUI is an important part of software application programming. Its goal is to enhance the efficiency and ease of use for the underlying logical design of a stored program, a design discipline known as usability. Techniques of user-centered design are used to ensure that the visual language introduced in the design is well tailored to the tasks it must perform.

In this work a graphical user interface had been designed under the usability criteria and based in HTML code. The goal is to create a method to communicate using exclusively the click actions. As the motivation of this system are motor disabled people, it's clear that the heal status is decreasing so they need ways to express ideas, answer simple questions and represent pain areas.

The Figure 6 shows the main page, where the user can choose a page to answer affirmative/negative; a page to put paint points over a human figure to locate pain areas; and finally one page with a virtual keyboard where the user can write sentences.

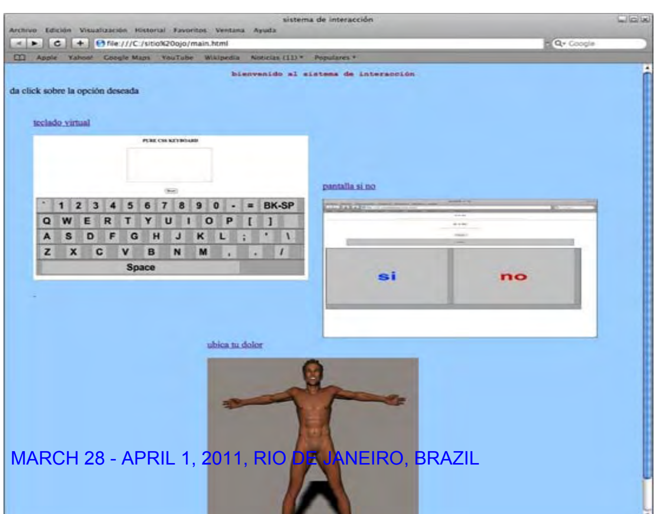


Fig. 6. Graphical user interface

F. Cost

Most of the available commercial human-computer interfaces for disables are not cheap, usually the cost is up to $2700 USD[15]. For this work our goal is to make a low cost system, helped by the decrease prices in computer technology, making it available to develop.

The table 1 shows the implementation cost of the system developed

| *Description* | *Price (USD)* |
|---|---|
| Head mount (materials) | 90 |
| Web cam (genius311r with LED's) | 40 |
| Accelerometer with rs323 interface | 70 |
| **Total** | **200** |

Table 1. Implementation cost

The table does not include the computer. The computer price is relative to manufacturer and characteristics. This work had been developed in a computer HP Pavilion w5040la. Any other computer with superior characteristics could be used.

## III. RESULTS

Using not disabled people the first application evaluation consisted in measuring the error respect classified eye gaze points keeping at all times the head without movements.

The confusion matrix presented in figure 7 and 8, represent a simple test where the user stare a specific point after the calibration, the system response with a classification of the eye gaze according 12 different classes. This test had been used to measure the accuracy of the system.

**confusion matrix**

| | output class | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| input class | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | 200 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 200 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 200 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 200 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 200 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 199 | 1 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 200 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 199 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 193 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 194 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 198 | 0 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 197 |

Figure 7. confusion matrix without compensation


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Achieving efficiency of 99% it is assumed that the control is high accurate.

In the other hand the same test was developed allowing head movements, to probe the compensation by the accelerometer.

**confusion matrix**

| | output class | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| input class | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | 198 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 191 | 3 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 195 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 192 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 |
| 5 | 10 | 0 | 0 | 0 | 190 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 8 | 0 | 0 | 3 | 187 | 2 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 15 | 0 | 0 | 3 | 176 | 6 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 12 | 0 | 0 | 1 | 176 | 0 | 0 | 0 | 11 |
| 9 | 0 | 0 | 0 | 0 | 17 | 1 | 0 | 0 | 180 | 2 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 22 | 11 | 0 | 3 | 164 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 9 | 0 | 0 | 164 | 13 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 11 | 183 |

Figure 8. Confusion Matrix with head tilt compensation

Figure 8 shows accuracy of 91% when the sensor compensate the eye gaze points.

The system response at 0.24 seconds peer command. This mean that each 0.24 seconds the system set the computer's in a new position or execute the click action.

A test user group formed by 15 non disabled people with visual acuity of 20/20, showing 93% of availability to control the system efficiently.

With an average time of 7 minutes to write a 2 word sentence, 5.9 minutes to accurate locate a pain point and 37 seconds to answers simple questions.

Finally, the application was tested with motor disabled people where 2 of 3 people were able to use the system, the user that can't use it, was due to an astigmatism problem. All these users expressed a comfortable felling using the system.

## IV. Discussion

Our primary goal was to develop an alternative to communicate for motor disabled people. In this paper it had been shown that it can be accomplished by looking at just one's eye movement. Our eye detection system can extract fast and accuracy the eye gaze and also compensate head tilt positions efficiently. Nevertheless not all the possible head movements has been considerate.

Some works uses video image processing of face to measure head tilt and head rotation. Nevertheless it represents processing time and the use of a second camera. The present work shows that is possible to manipulate the computer's cursor accuracy with only one camera and one accelerometer.

Users with astigmatism are no able to use the system, due the poor capacity to look clearly the screen, resulting in a low recognition of characters and figures. Also the system does not allow the use of eyeglasses.

As an alternative form of communication, the present shows functionality, but the execution time is not to good as desired, thats because the computer's cursor moves slowly according the classified class and makes that the complete travel over the screen takes a long time. It might be possible that as more as the user uses the system, user improve movements skills to have better execution times. Future works must measures skills and their learning curves to prove that statement.

## V. Conclusion

This work developed a communication system based on voluntary ocular movements at low cost and high performance, the system was developed with all the safety requirements.

Ergonomic design, low cost, and lightweight are some of the principal characteristics of the head mounting system.

The eye gaze position algorithm based on lateral histogram and the use of neural networks present an accuracy higher than 90%. This new methodology reduce the processing time respect other methods.

The use of the accelerometer bring us some features to compensate head movements, by itself still being insufficient. Even that the system performance accuracy is higher than 80%.

Usability criteria had been applied in the design of the graphical user interface showing easy navigation trough the different windows, and allowing a slowly but correct communication in the real world.

Finally in words of the motor disabled users the system integrates them in someway, to the real world, but also integrates them in the ciber-world as they have the capacity of navigation and control over computers operative system including web browsers and some videogames.

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