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Wheelchair Guidance Strategies Using EOG

R. BAREA, L. BOQUETE, M. MAZO and E. LÓPEZ
Electronics Department, University of Alcalá, Alcalá de Henares, Madrid, Spain;
e-mail: barea@depeca.uah.es

Abstract. This paper describes an eye-control method, based on electrooculography (EOG), for guiding and controlling a wheelchair for disabled people; the control is actually effected by eye movements within the socket. An eye model based on an electrooculographic signal is proposed and its validity is studied. Different techniques and guidance strategies are then shown with comments on the advantages and disadvantages of each one. The system consists of a standard electric wheelchair with an on-board computer, sensors and a graphic user interface run by the computer. This control technique could be useful in multiple applications, such as mobility and communication aid for handicapped persons.

Key words: electrooculography (EOG), wheelchair, control, guidance, graphical interfaces, disabled people.

1. Introduction

In the European Union there are about 80 million elderly or disabled people [15]. Various reports also show that there is a strong relation between the age of the person and the handicaps suffered, the latter being commoner in persons of advanced age. Given the growth in life expectancy in the EU, this means that a large part of its population will experience functional problems. Aware of the dearth of applications for this sector of the population, governments and public institutions have been promoting research in this line in this recent years. Various types of research groups at a world level have begun to set up cooperation projects, projects to aid communication and mobility of elderly and/or disabled persons with the aim of increasing their quality of life and allowing them a more autonomous and independent lifestyle and greater chances of social integration [13, 16].

In recent years there has been an increase in the development of assistive technology for people with several disabilities, and great strides have been made in communication systems between humans and machines. These advances have been made mainly in communications from machines to humans, by means of graphical user interfaces or multimedia applications (sounds). However, these advances in the communication from humans to machines have been modest, using keyboards, mice, joysticks or tactile screens. All these systems are manual. At the moment, many communication systems are being developed based on voice recognition or visual information [8] and they will be launched onto the market in the coming years. For example, people daily make a lot of eye movements that allow them to do different tasks, such as reading, writing, learning new things, acquiring information about the environment, handling objects and communicating with other people, etc. This ability of people to control their gaze direction can be used to communicate with the machines.

Moreover, the growing use of the computer, both in work and leisure, has led to the development of PC-associated handling applications, mainly using graphic interfaces. Many systems have thus been developed for handling the PC mouse, ranging from systems based on videooculography (VOG) [4], controlling a mouse using an infrared head-operated joystick [5] and even the design of an electrooculographic mouse [3]. All these applications, duly tailored to the user thereof, allow graphic interfaces to be used in the control of many different applications.

One of the most potentially useful applications for increasing the mobility of disabled and/or elderly persons is wheelchair implementation. A standard motorised wheelchair aids the mobility of disabled people who cannot walk, always providing that their disability allows them to control the joystick safely. Persons with a serious disability or handicap, however, may find it difficult or impossible to use them; cases in point could be tetraplegics who are capable only of handling an on–off sensor or make certain very limited movements, such as eye movements. This would make control of the wheelchair particularly difficult, especially on delicate manoeuvres. For such cases it is necessary to develop more complex human-wheelchair interfaces adapted to the disability of the user, thus allowing them to input movement commands in a safe and simple way. Among all these types of interfaces, the least developed ones at the moment are those based on visual information, due mainly to the vast amount of information that needs to be processed. One form of communication that is of particular interest here is the detection and following of the eyegaze or eye control systems.

A study on the group of persons with severe disabilities shows that many of them retain intact their control capacity over the oculomotor system, so eye movements could be used to develop new human–machine communication systems. Furthermore, this type of interface would not be limited to severely disabled persons but could be extended to the whole group of persons with the capacity for controlling their eye movements.

One of the main motives behind this research work has therefore been the aim of making a contribution towards satisfying the technological needs of potential wheelchair users by designing an eye-movement guidance system for severely disabled persons, with an economic and functional feasibility that would enable them to improve their quality of life. As will be seen later, the objective of this work is to implement a wheelchair guidance system based on electrooculography techniques.

This paper has been divided into sections to match the main areas of the research work itself: Section 2 describes electrooculography (EOG) as a technique for recording the electrical activity of the eyeball and its validity for detecting eye movements. A study is also made of the problems involved in recording the EOG. Section 3 proposes an electrooculographic model of the eye for determining the eye position in terms of the recorded EOG. Section 4 deals with different wheelchair guidance strategies by means of electrooculography and shows the electrooculographic system actually set up, describing the test platform (wheelchair), the user-wheelchair audio-visual communication system and the various electrooculographic guidance interfaces. All this is rounded out by diverse guidance tests and the results thereof, given in Section 5. Finally, Section 6 draws the main conclusions and points to future research work.

2. Electrooculography

Electrooculography is a method for sensing eye movement and is based on recording the standing corneal-retinal potential arising from hyperpolarisations and depolarisations existing between the cornea and the retina; this is commonly known as an electrooculogram [10]. This potential can be considered as a steady electrical dipole with a negative pole at the fundus and a positive pole at the cornea (Figure 1). The standing potential in the eye can thus be estimated by measuring the voltage induced across a system of electrodes placed around the eyes as the eyegaze changes, thus obtaining the EOG (measurement of the electric signal of the ocular dipole).

The EOG value varies from 50 to 3500 μV with a frequency range of about DC-100 Hz. Its behaviour is practically linear for gaze angles of $\pm 30°$. It should be pointed out here that the variables measured in the human body (any biopotential) are rarely deterministic. Their magnitude varies with time, even when all possible variables are controlled. Most of these biopotentials vary widely between normal patients, even under similar measurement conditions. This means that the variability of the electrooculogram reading depends on many factors that are difficult to

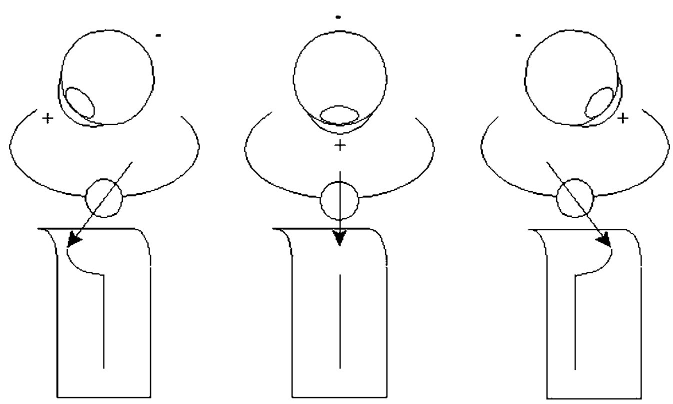


Figure 1. Ocular dipole.

determine: perturbations caused by other biopotentials such as EEG (electroencephalogram), EMG (electromiogram), in turn brought about by the acquisition system, plus those due to the positioning of the electrodes, skin-electrode contacts, lighting conditions, head movements, blinking, etc. In [11] various studies were made of the accuracy and precision of the EOG in tracking the eyegaze.

To eliminate or minimise these defects, therefore, a considerable effort had to be made in the signal acquisition stage to make sure it is captured with the minimum

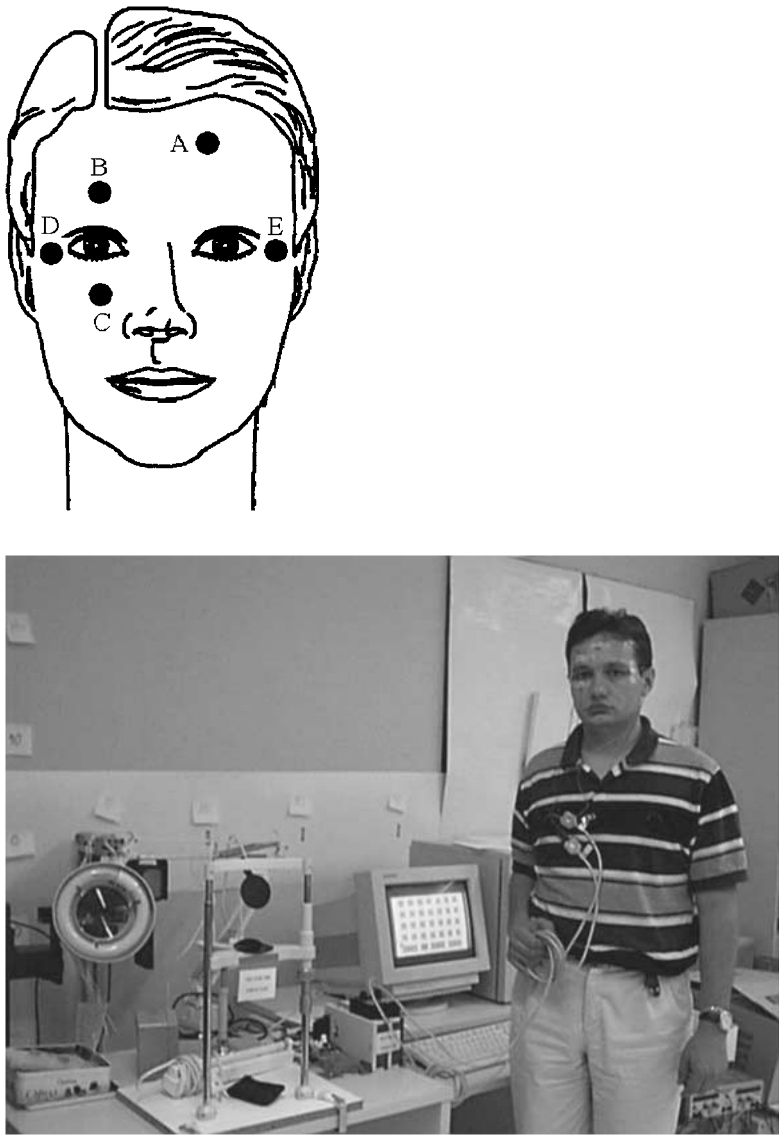


Figure 2. Electrodes placement: A – reference electrode, D, E – horizontal derivation electrodes, B, C – vertical derivation electrodes.

possible perturbations and then during the study and processing thereof to obtain the best possible results.

2.1. ELECTROOCULOGRAM ACQUISITION

The electrooculogram (EOG) is captured by five electrodes placed around the eyes, as shown in Figure 2(a). The EOG signals are obtained by placing two electrodes to the right and left of the outer canthi (D, E) to detect horizontal movement and another pair above and below the eye (B, C) to detect vertical movement. A reference electrode is placed on the forehead (A). The EOG signal changes approximately 20 μV for each degree of eye movement. In our system, the signals are sampled 10 times per second. The EOG signal is a result of a number of factors, including eyeball rotation and movement, eyelid movement, different sources of artefact such as EEG, electrode placement, head movements, influence of the illumination, etc. It is therefore necessary to eliminate the shifting resting potential (mean value) because this value changes. To avoid this problem an AC high-gain differential amplifier (1000–5000) is used, together with a high pass filter with cut-off frequency at 0.05 Hz and relatively long time constant and a low pass filter with cut-off frequency at 35 Hz. Ag-AgCl floating metal body-surface electrodes are also used.

An indication is given below of the wave forms for a signal captured for different eyegaze angles in the horizontal direction. Figure 3 shows the eyegaze sequence and Figure 4 the EOG values obtained with and without a 0.05 Hz filter. Figure 4 shows that it is possible to detect variations in the eyegaze direction by changes in the value of the EOG signal.

3. Eye Model Based on EOG (BiDiM-EOG)

Our aim is to design a system capable of obtaining the gaze direction by detecting the eye movements. The oculomotor system is modelled with the eye position within its socket as the output variable, i.e., the eye position with respect to the craneum θ_o-θ_{cr}, although this angle is usually represented by the deviation angles with respect to the eye's central position $\theta_{Horizontal}$ y $\theta_{Vertical}$ (Figure 5). This variable can be obtained by different methods, such as videooculography (VOG) [9], infrared oculography (IOR), scleral coil (SC) [6], etc. Here, however, it is going to be modelled in terms of the electrooculographic signal (EOG).

In view of the physiology of the oculomotor system, the modelling thereof could be tackled from two main viewpoints:

(a) Anatomical modelling of the gaze-fixing system, describing the spatial configuration thereof and the ways the visual information is transmitted and processed;

(b) modelling of the eye movements, studying the different types of movements and the way of making them.

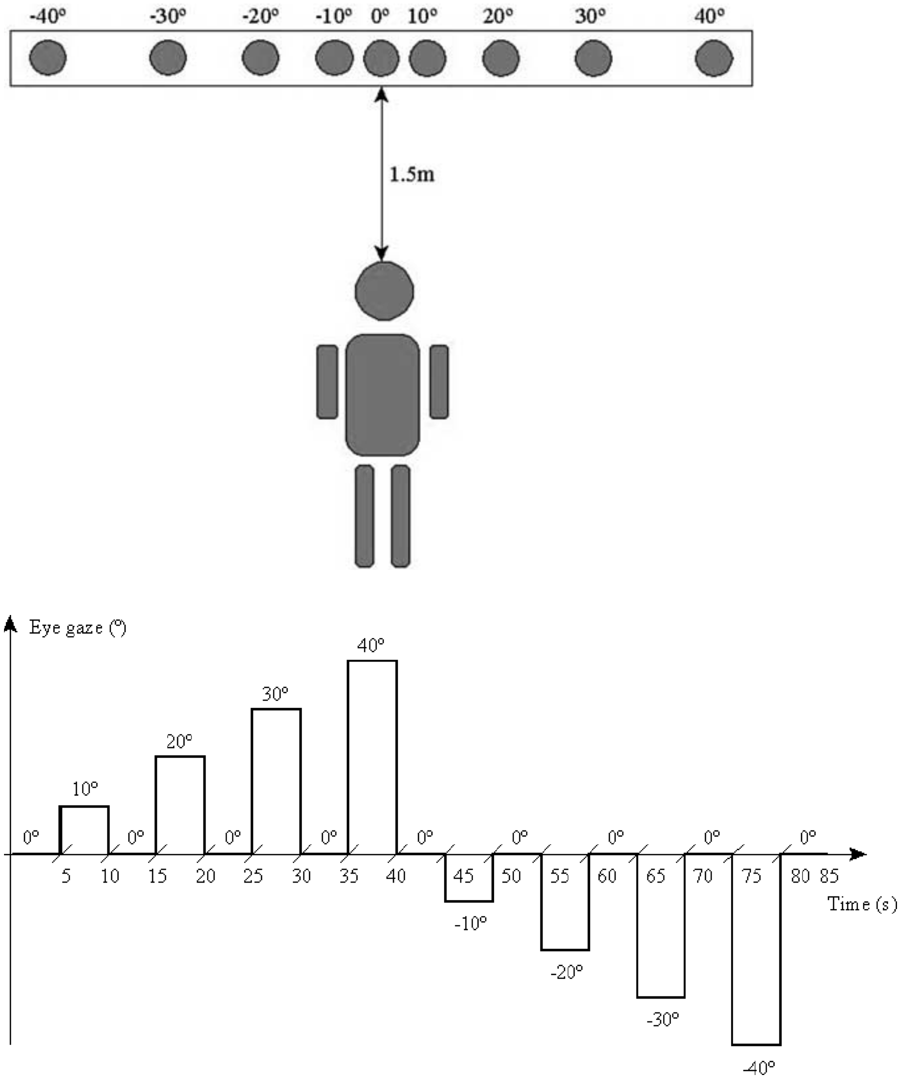


Figure 3. Eyegaze sequence.

On the basis of the physiological and morphological data of the EOG, an electro-oculography-based model of the oculomotor system is proposed (Figure 7) (Bidimensional dipolar model EOG, BiDiM-EOG). This model allows us to separate saccadic and smooth eye movements and calculate the eye position in its socket with good accuracy (error of less than 2°). The filter eliminates the effects due to other biopotentials, just as the blinks over to the EOG signal. The security block detects when the eyes are closed, whereupon the output is disabled. The EOG signal is then classified into saccadic or smooth eye movements by means of two detectors. If a saccadic movement is detected, a position control is used,

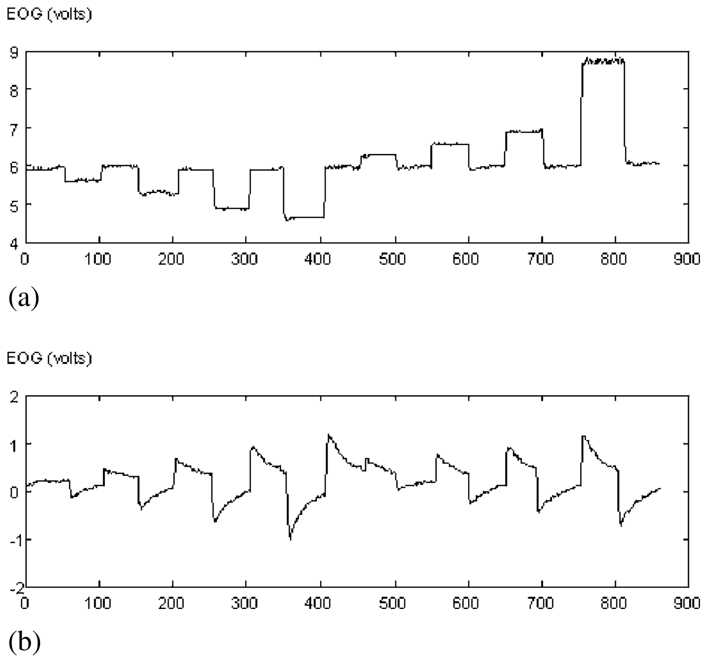


Figure 4. (a) Horizontal EOG signal with continuous component. (b) Horizontal EOG signal with HPF 0.05 Hz.

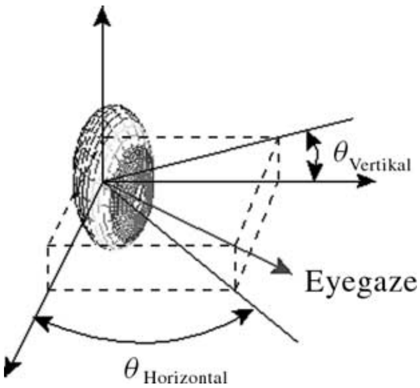


Figure 5. Eye placement into its orbit.

whereas if a smooth movement is detected, a speed control is used to calculate the eye position. The final position (angle) is calculated as the sum of the saccadic and smooth movements. The model also has to adapt itself to the possible variations of acquisition conditions (electrode placement, electrode-skin contact, etc.). To do so, the model parameters are adjusted in accordance with the angle detected.

A person can voluntarily make only saccadic movements unless he/she tries to follow an object in movement. Therefore, to control an interface the study should

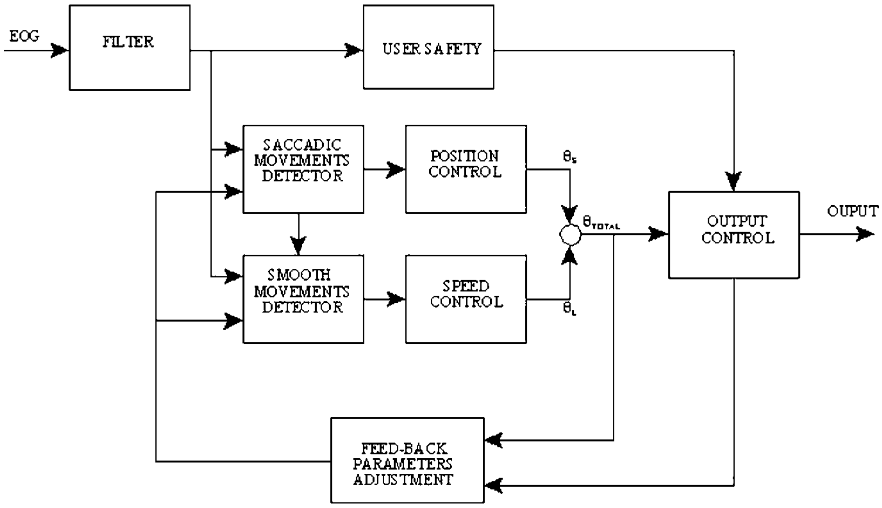


Figure 6. Bidemensional bipolar model (BiDiM-EOG).

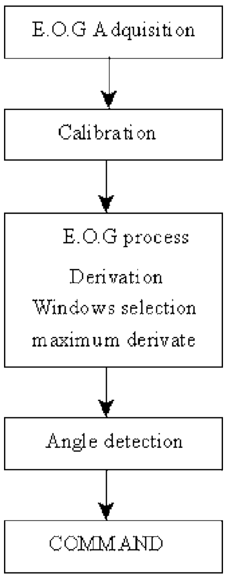


Figure 7. Process to detect saccadic movements.

be focused on the detection of saccadic movements (rapid movements). This process can be done by processing the derivative of the EOG signal. To avoid signal variability problems (the isoelectric line varies with time, even if the user keeps the gaze at the same position), a high pass filter with a very small cut-off frequency (0.05 Hz) is used. The process can be observed in Figure 7. Figure 8 shows the results of a process in which the user made a sequence of saccadic movements of ±10° to ±40°. This proves that the derivative of the electrooculographic signal

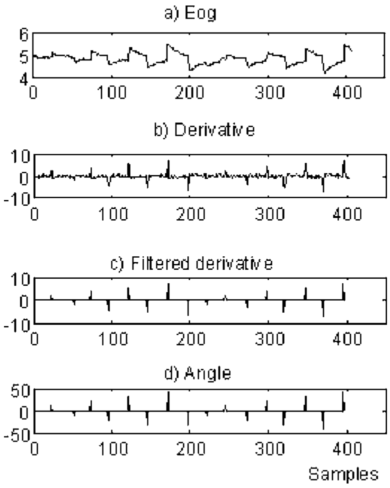


Figure 8. Process results.

allows us to determine when a sudden movement is made in the eyegaze. This variation can be easily translated to angles (Figure 8(d)).

The following sections give the results obtained to date in the Electronics Department of the University of Alcalá. This technique can be used to help disabled people, since we have obtained an accuracy error of less than $\pm 2°$. Although in this paper we are going to comment on the results obtained in the guidance of a wheelchair (mobility aid), other applications have been developed to increase communication facilities (communication aid) [2, 12].

4. Guidance of a Wheelchair Using Electrooculography

The goal of this control system is to guide an autonomous mobile robot using EOG signals generated from eye movements within the socket [1, 7]. In our case, the autonomous robot is a wheelchair for disabled people; Figure 9 shows a diagram of the control system. The EOG signal is recorded by means of an acquisition system and the data are sent to a PC, in which they are processed to calculate the eyegaze direction using a inverse model of the eye. This then serves as the basis for drawing up the control strategy for sending the wheelchair control commands. There commands are sent to a controller that implements the high-level control and generates the linear and angular speed commands of the wheelchair ($[V_{\mathrm{cmd}} \quad \Omega_{\mathrm{cmd}}]^T$). The wheelchair's kinematic model then transforms these speeds into angular speeds for each wheel ($[\omega_{\mathrm{r,cmd}} \quad \omega_{\mathrm{l,cmd}}]^T$) and they are sent to a low-level control module where two close-loop speed controls are implemented. As can be seen, the system also has an audio-visual feedback system, with a tactile screen positioned in front of the user and a speaker (Figure 10).

Several security elements are necessary, such as alarm and stop commands, to avoid dangerous situations. These codes can be generated by means of the

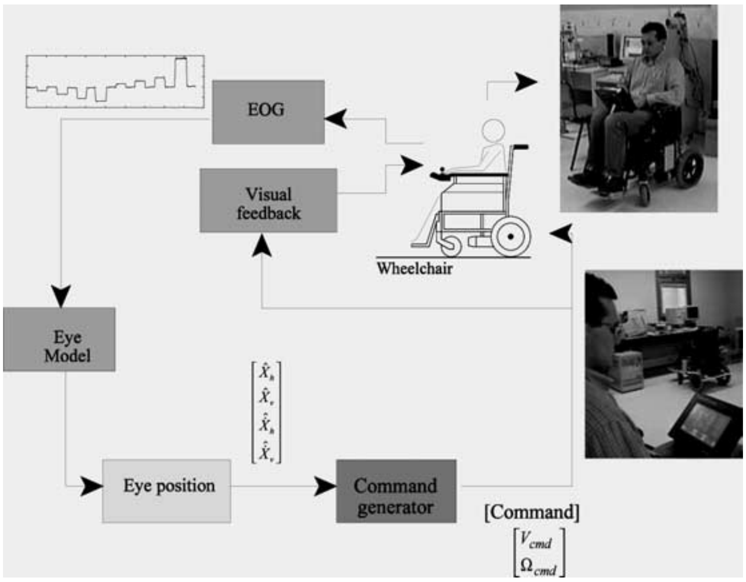


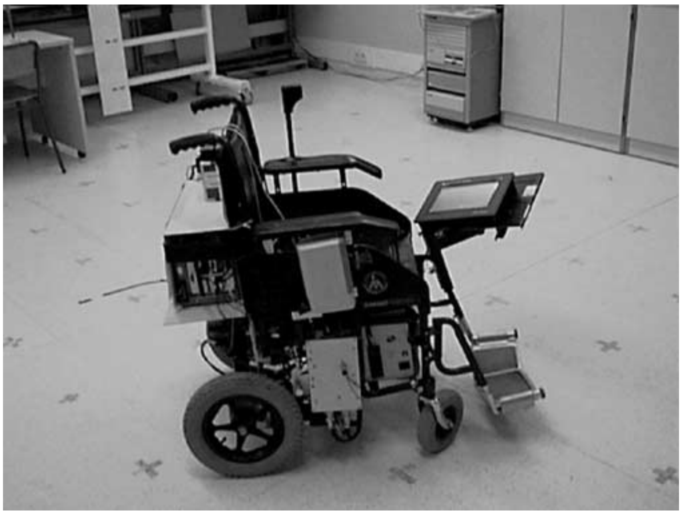
Figure 9. Control.

blink and alpha waves in EEG to detect when the eyelids are closed. The automatic wheelchair system must also be able to navigate in indoor and outdoor environments and should switch automatically between navigation modes for these environments. Therefore, this system can be applied to different navigation modes depending on the disability degree of the user, always using the most efficient technique for each person. Different support systems have to be used for avoiding collisions ("bumpers", ultrasonic and infrared sensors, etc.) and the robotic system can automatically switch over to controlling the system in an autonomous way. For example, if the user loses control and the system becomes unstable, the wheelchair should step in and take over the control system. This work is included in a general purpose navigational project for a wheelchair mobility aid system; this project is the SIAMO project [14].

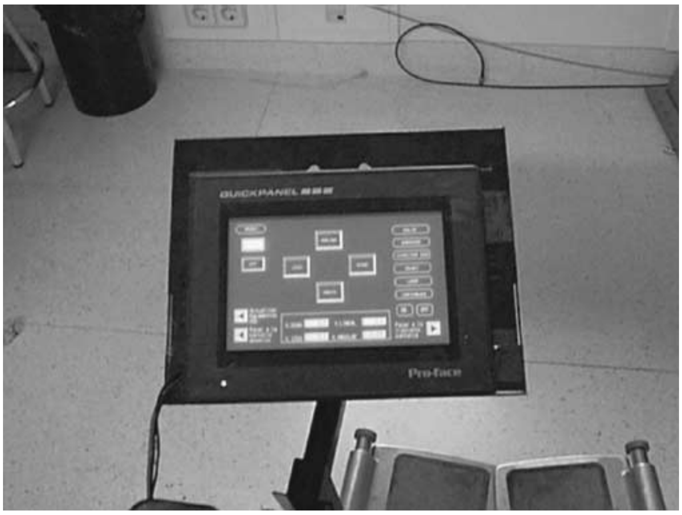
The wheelchair can be controlled by various guidance strategies: direct access guidance, guidance by automatic or semiautomatic scanning techniques, guidance by eye commands. Comments are made below on the main features of each one.

4.1. DIRECT ACCESS GUIDANCE

This system gives direct access to the desired command. The user, shown a certain graphic interface, selects the desired command by positioning a given cursor over it and then effecting a given validation action. The drawback of this interface is the Midas Touch problem: the human eye is always ON and is therefore always looking somewhere. Everywhere the user looks, another command is activated.



(a)



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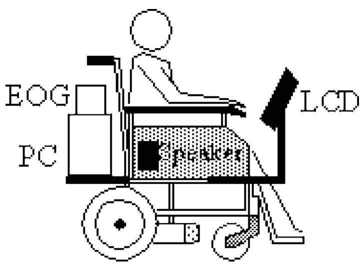

(c)

Figure 10. Audio-visual feedback.

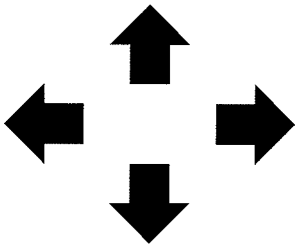

Figure 11. Direct access interface.

This guidance strategy can hence be of use only in supervised applications, since the system does not guarantee the safety of the user in the event of a loss of control.

Another drawback of this technique is that the screen showing the interface has to be in front of the user and might thus balk visibility of the trajectory to be followed in guidance applications. This makes it necessary for users to move their head (some of whom, with certain types of injury, are unable to do so) and it also means that the position of the head vis-à-vis the interface is lost, thus upsetting the calibration of the system.

Figure 11 shows the user guidance interface. Commands should be as big as possible with no overlapping, in the interests of the best selection thereof; there should also be certain safety areas that make it impossible to select one command when another is desired.

As can be seen the main advantage of this interface is its simplicity and ease of assimilation; the training and learning time is therefore almost nil. The set of possible commands are:

- FORWARDS: The robot's linear speed picks up (the wheelchair moves forward).
- BACKWARDS: The robot's linear speed decreases (the wheelchair moves backwards).
- RIGHT: The angular speed increases (the wheelchair moves to the right).
- LEFT: The angular speed decreases (the wheelchair moves to the left).

The commands are also mutually exclusive. Figure 12 shows the resultant action on the wheelchair's speed. Note that a fixed speed per event is assigned. The maximum gradient and values of the linear and angular speeds of the wheelchair have to be customised for each user.

An example is given below of this type of guidance, showing how the selected interface command is selected, the displacement of the cursor depending on the detected electrooculographic potential (Figure 13).

4.2. SCANNING GUIDANCE

In this system the user accesses the desired command by scanning all the established guidance commands. The user is presented with a screen showing diverse

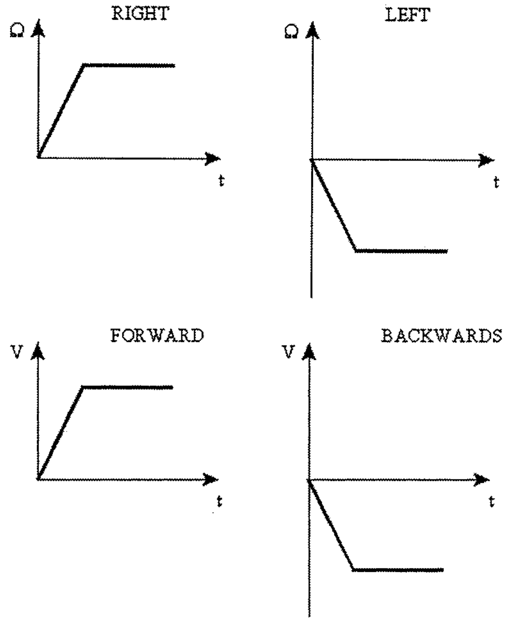

Figure 12. Guidance speeds.

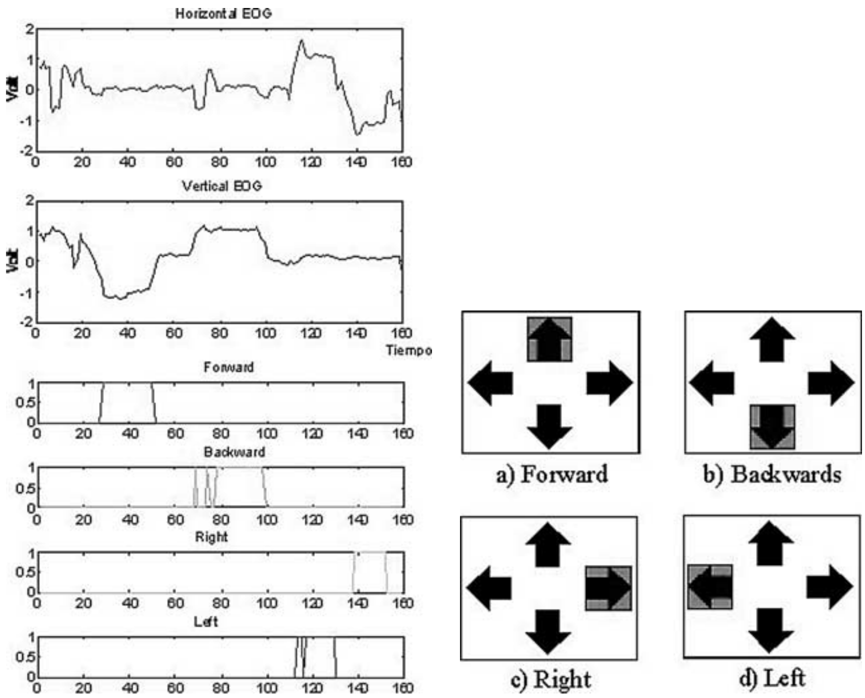

Figure 13. Direct access guidance strategy.

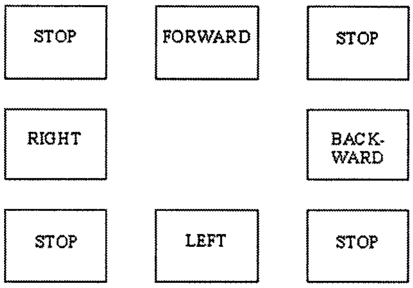

Figure 14. Interface of scanning guidance.

commands and each one is activated, either semiautomatically or automatically until the desired one is selected.

This type of interface is ideal for persons with little precision in their eye movements, although they do need to have certain control over them to be able to generate the validation actions. The interface developed on this basis is shown in Figure 14.

As can be seen the set of commands is small:

- STOP: The robot stays still.
- FORWARDS: The robot's linear speed increases (the wheelchair moves forward).
- BACKWARDS: The robot's linear speed decreases (the wheelchair moves backwards).
- RIGHT: The angular speed increases (the wheelchair moves to the right).
- LEFT: The angular speed decreases (the wheelchair moves to the left).

The directional commands are integrated into the BACKWARDS and FORWARDS commands, which, besides governing the linear speeds, also establish the wheelchair's direction. The speed commands are integrated into the BACKWARDS, FORWARDS, RIGHT and LEFT commands, which generate the corresponding linear and angular speeds as shown in Figure 12.

Command generation is codified by a state machine defining the time-dependent state (command) of the system, as shown in Figure 15. With the semiautomatic guidance strategy it is the users themselves that have to scan the various commands and also effect a certain "action". The user can thus move over the active commands until settling on the desired one. Once selected it has to be validated, by an action or by simple lapse of time. In this case time-validation has been opted for; i.e., if a given command remains selected for a given period of time, it is then validated and the associated control action is executed. The validation time interval has to be adapted to the characteristics of each user.

A validation example is shown in Figure 16. Note that a semiautomatic scan is effected until selecting the command LEFT. Once selected, no other actions are performed for a given interval of time and the command is thereby validated,

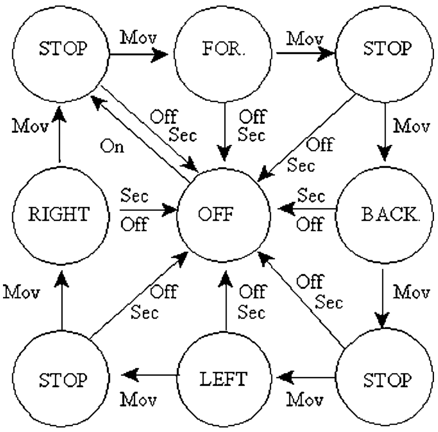

Figure 15. State machine.

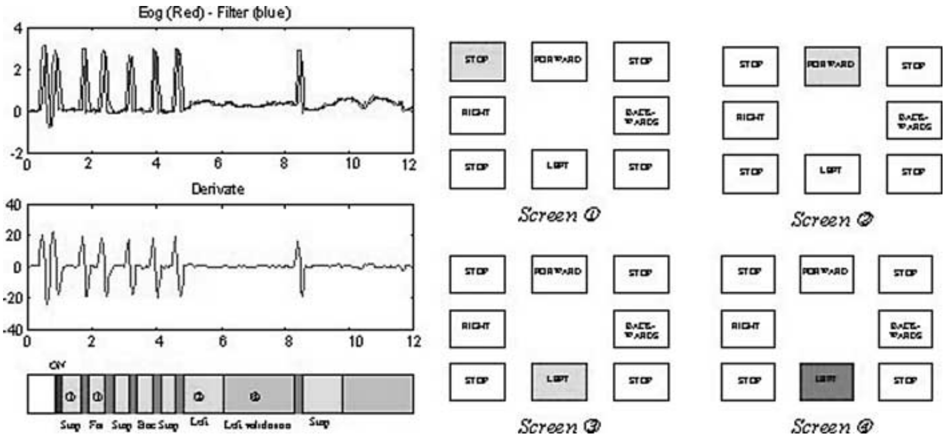

Figure 16. Selection of LEFT command using semiautomatic scan.

the corresponding angular guidance speed then being generated. The command is deactivated when another movement action is executed.

4.3. GUIDANCE BY EYE COMMANDS

The aim of this technique is to develop control strategies based on certain eye movements (ocular actions) and their interpretation as commands. This type of interface can be used by those persons who can control their eye movements and at the same time make different movements voluntarily.

This type of control aims to simulate the intuitive control of a non-disabled person when driving a car. In this control (imagine driving a car) the linear speed is controlled by the accelerator and the angular speed by turning the steering wheel. The objective of this process is to control at all times the angular and linear speeds of the wheelchair. The above-mentioned movement commands are therefore effected by means of the following actions:

UP: Increase in linear speed ($V++$).
DOWN: Decrease in linear speed ($V-$).
RIGHT: Increase in angular speed ($W++$).
LEFT: Decrease in angular speed ($W-$).

It can be appreciated that this control method has to allow for independent adjustment of the increases and decreases of angular and linear speeds to bring them into line with the characteristics or capacities of the user. These variable speed values determine the rapidity with which the robot changes the trajectory it is following. Methods for controlling this variation are therefore vital, such as nonlinear speed increases or decreases or change to a state of repose for the robot guidance to be begun again from zero speed.

An example is given below of this type of command generator for a control sequence (Figure 17) and the trajectory followed in the case of $I_V = 100$ mm/s and $I_W = 0.2$ rad/s (Figure 18). It will be observed that first of all the activation command is activated, after which the speed is kept under control. The linear speed is increased and then the angular speed to describe a curve to the right. After the turn, a straight trajectory is re-established and then the wheelchair is brought to a halt.

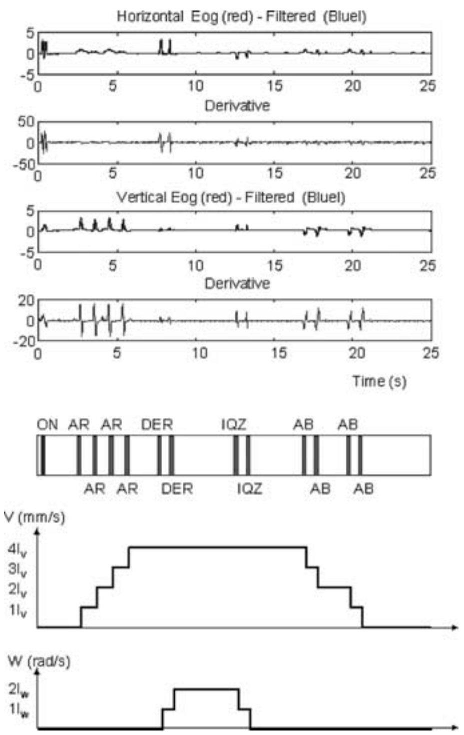

Figure 17. Guidance by eye commands.

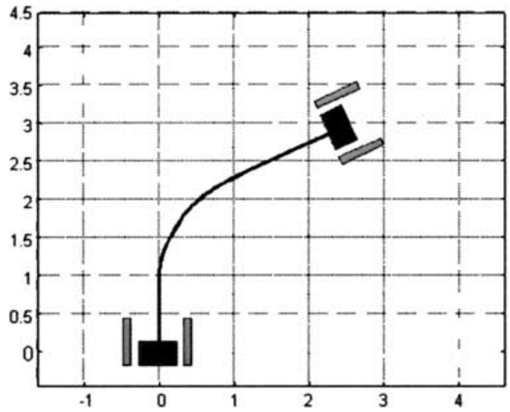

Figure 18. Trajectory followed.

5. Results

A period of previous training is necessary to learn to guide a wheelchair by EOG techniques. For this reason a 2D electrooculographic simulator has been developed.

Two examples of semiautomatic scan guidance are shown in Figure 19, where the grey line represents the "3-spline curve-line" to follow. This trajectory is obtained using a trajectory spline generator developed in the SIAMO project. The black line, for its part, represents the trajectory obtained when the wheelchair is guided using EOG. The figure shows that the desired trajectory is followed with a small lateral error. This system has to be learnt as an acquired skill. Studies have shown that disabled persons usually require about 15 minutes to learn to use this kind of system [17].

After the guidance learning process the person can progress to the real guidance of the wheelchair. Figure 20 gives an example of eye-command guidance carried out in the Electronics Department of the University of Alcalá, showing the trajectory followed and sundry images corresponding to different instants of this guidance.

6. Conclusions

In this paper, the main characteristics of electrooculography have been shown: acquisition and processing of the EOG signal and its applications in assistive systems for the disabled. An eye model based on EOG is proposed and a study is made of its ability to determine the eye position within the socket. It is also possible to codify ocular actions as commands and apply them to mobility and communication assistive applications for handicapped persons. In this work, we present a control system that allows the handicapped, especially those with only eye-motor coordination, to live more independently. Some of the previous wheelchair robotics research has been restricted to a particular location and in many areas of robot-

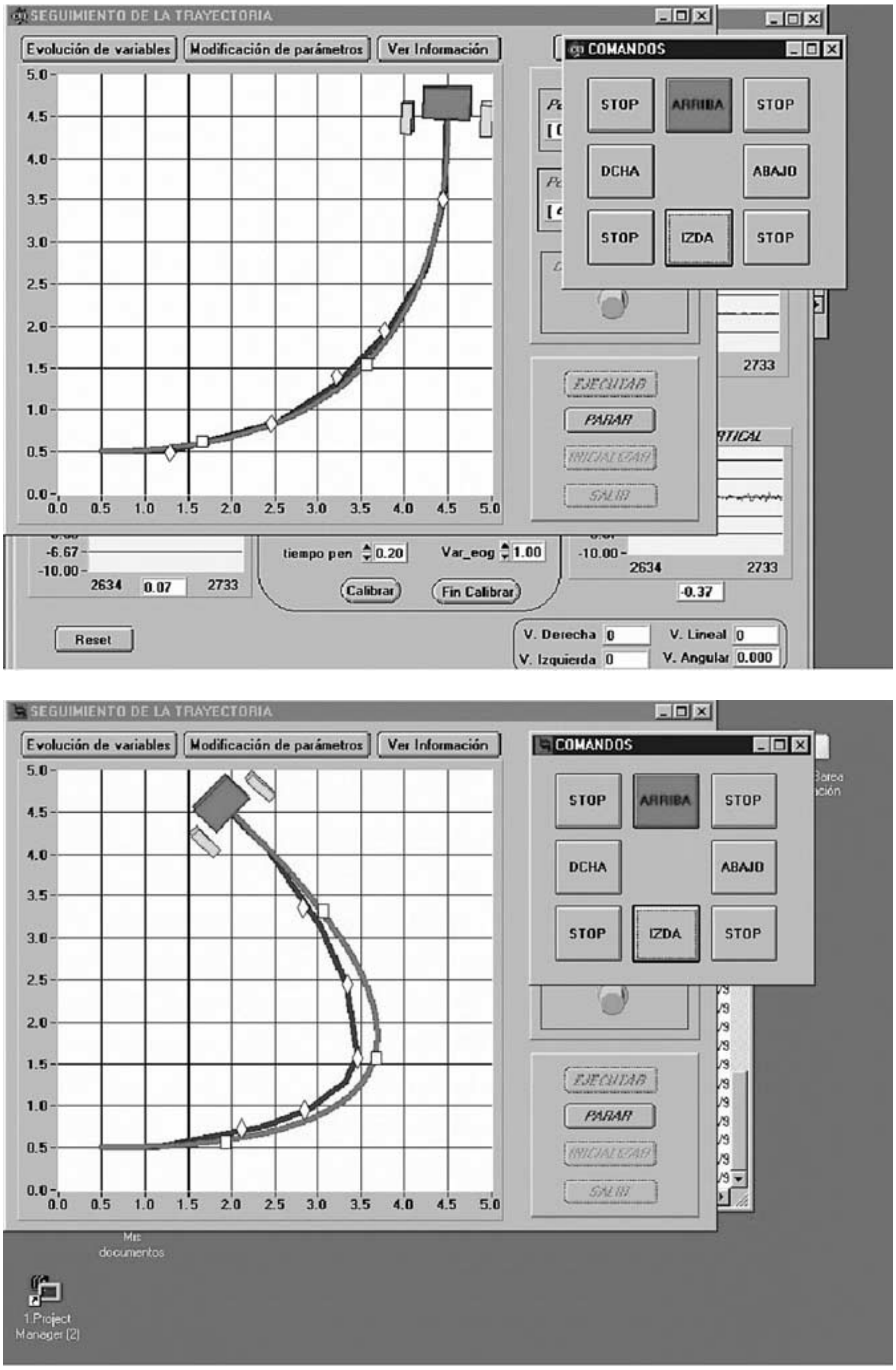

Figure 19. Examples of wheelchair guidance.

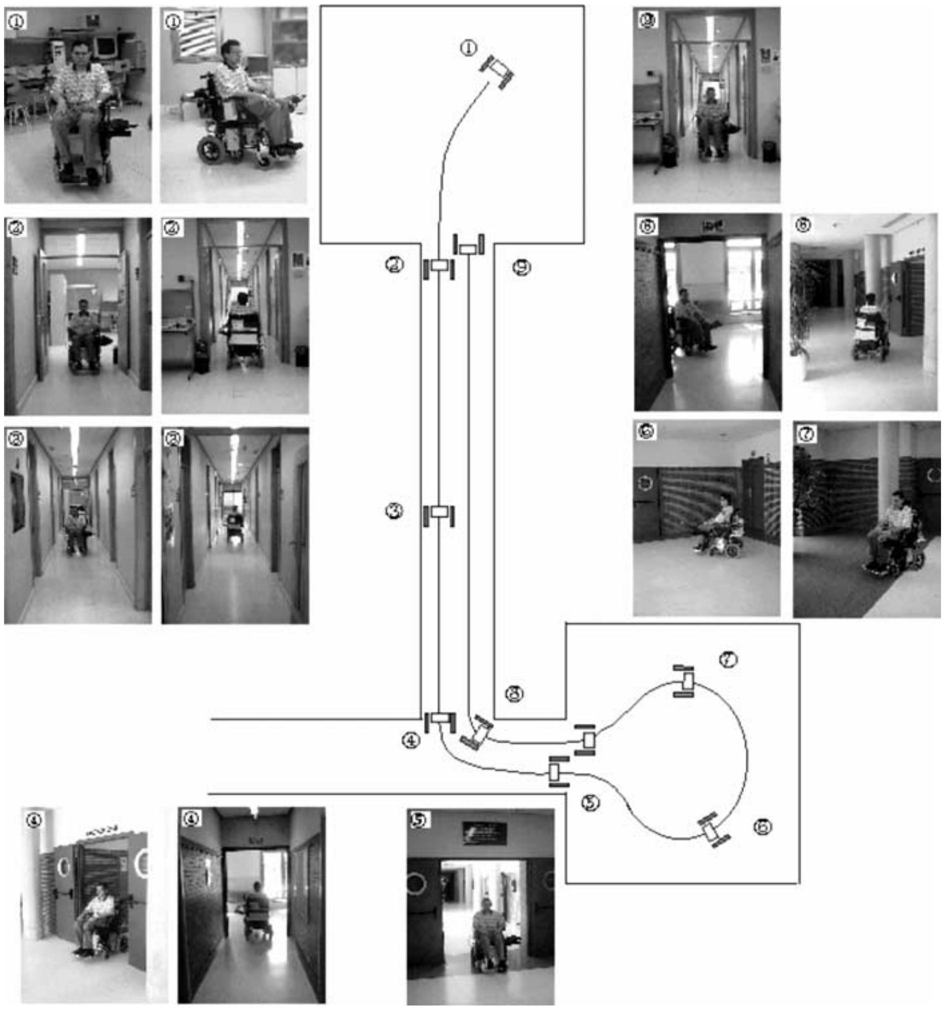

Figure 20. Example of eye-command guidance.

ics, environmental assumptions can be made that simplify the navigation problem. However, a person using a wheelchair and EOG techniques should not be limited by the assistive device if the environment has objects in the requested path.

The results obtained in the learning and training period show that the required time is very reduced, being able to have a good control of the system in inferior times at half an hour. Nevertheless, these times vary in the user's possibilities, their disabilities and their skill when controlling the system. These results are successfully due mainly to the simplicity of the guidance commands set and to the easy realization of the ocular actions (eye movements) associated to the same ones.

Many applications can be developed using EOG because this technique provides the users with a degree of independence in the environment. Therefore, any improvement in the convenience of this technique could be of great potential utility and help in the future. If the eye gaze is known, various user interfaces can then be developed to control different tasks: spell and speak software programs allow users to write a letter or a message, after which a control system can interpret the message and generate different commands. A similar code can be generated for deaf people, etc.

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References

1. Barea, R., Boquete, L., Mazo, M., and López, E.: Guidance of a wheelchair using electrooculography, in: *Proc. of the 3rd IMACS Internat. Multiconference on Circuits, Systems, Communications and Computers (CSCC'99)*, July 1999, Greece.
2. Barea, R., Boquete, L., Mazo, M., López, E., and Bergasa, L.: Aplicación de electrooculografía para ayuda a minusválidos, *Revista Española de Electrónica* (October 1999) (in Spain).
3. Barea, R., Boquete, L., Mazo, M., López, E., and Bergasa, L. M.: Diseño de un ratón electrooculográfico, in: *SAEEI'00.V Seminario Anual de Automática*, Electrónica Industrial e Instrumentación, Tarrasa, 2000.
4. ERICA Project, Eyegaze Response Interface Computer Aid System, ERICA Inc.
5. Evans, D. G., Drew, R., and Blenkhorn, P.: Controlling mouse pointer position using an infrared head-operated joystick, *IEEE Trans. Rehabilitation Engrg.* **8**(1) (2000).
6. Ferman, L., Collewijn, H., Jansen, T. C., and van den Berg, A. V.: Human gaze stability in the horizontal, vertical and torsional direction during voluntary head movements, evaluated with a three-dimensional scleral induction coil technique, *Vision Research* **27** (1987), 811–828.
7. Gips, J., DiMattia, P., Curran, F. X., and Olivieri, P.: EagleEyes Project, Computer Science Department, Boston College, Chestnut Hill, MA, USA.
8. Jacob, R. J. K.: Eye movement-based human–computer interaction techniques toward non-command interfaces, Human–Computer Interaction Lab., Naval Research Laboratory, Washington, DC, 1995.
9. Lahoud, J. A. and Cleveland, D.: The eyegaze eyetracking system, LC Technologies, in: *4th Annual IEEE Dual-Use Technologies and Aplications Conference*, Suny Institute of Technology at Utica, Rome, New York.
10. Nicolau, M. C., Burcet, J., and Rial, R. V.: *Manual de Técnicas de Electrofisiología Clínica*, Universidad de las Islas Baleares, España, 1995.
11. North, A. W.: Accuracy and precision of electrooculographic recording, *Invest. Ophthalmol.* **4** (1965), 343–348.
12. Palazuelos, S., Aguilera, S., Rodrigo, J. L., Godino, J., and Martín, J.: PREDICE: Editor predictivo para personas con discapacidad física, *Jornadas sobre Comunicación Aumentativa y Alternativa, ISAAC*, Vitoria (September 1999) (in Spain).
13. Schilling, K., Roth, H., Lieb, R. and Stützle, H.: Sensors to improve the safety for wheelchair users, in: I. Placencia Porrero and E. Ballabio (eds), *Improving the Quality for the European Citizen*, IOS Press, 1998.

14. SIAMO Project, Sistema de Ayuda a la Movilidad (CICYT), Departamento de Electrónica, Universidad de Alcalá, Madrid, Spain.
15. Witte et al.: Heart programme, European Union.
16. Yanco, H. A., Hazel, A., Peacock, A., Smith, S., and Wintermute, H.: Initial report on wheelesley: A robotic wheelchair system, in: *Proc. of the Workshop on Developing AI Applications for the Disabled, Internat. Joint Conf. on Artificial Intelligence*, Montreal, Canada, August 1995.
17. Yanco, H. A. and Gips, J.: Drivers performance using single swicth scanning with a powered wheelchair: Robotic assisted control versus traditional control, in: *RESNA '98*, Pittsburgh, PA, MIT Artificial Intelligence Laboratory, Cambridge, MA, Computer Science Department, Boston College, Chestnut Hill, MA.