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System for Assisted Mobility Using Eye Movements Based on Electrooculography

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***Abstract*—This paper describes an eye-control method based on electrooculography (EOG) to develop a system for assisted mobility. One of its most important features is its modularity, making it adaptable to the particular needs of each user according to the type and degree of handicap involved. An eye model based on electrooculographic signal is proposed and its validity is studied. Several human-machine interfaces (HMI) based on EOG are commented, focusing our study on guiding and controlling a wheelchair for disabled people, where the control is actually effected by eye movements within the socket. 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. On the other hand, this eye-control method can be applied to handle graphical interfaces, where the eye is used as a mouse computer. Results obtained show that this control technique could be useful in multiple applications, such as mobility and communication aid for handicapped persons.**

***Index Terms*—Control, disabled people, electrooculography (EOG), eye movements, graphical interfaces, guidance, wheelchair.**

I. Introduction

In the European Union, it is estimated that 10–15% of the total population is disabled and the population aged 60 years and older have a ratio at nearly 1 person in 10. This means that in EU there are about 80 million elderly or disabled people [1]. Besides, 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 world (in the countries of the Organization for Economic Cooperation and Development (OECD) it is expected that the proportion of older persons aged 60 years and older will have reached a ratio of 1 person in 3 by the year 2030), 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 the 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 [2], [3].

In the last years, there has been a significant increase in the development of assistive technology for people with disabilities, improving the traditional systems. Also, 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. This way, the traditional methods of control or communication between humans and machines (joystick, mouse, or keyboard), that require a certain control motor on the part of the users, they are supplemented with others that allow their use for people with severe disabilities. Among these new methods it is necessary to mention voice recognition [4] or visual information [5]. For example, using voice recognition it is possible to control some instruments or applications by means of basic voice commands or write a text in “speech and spell” applications. Other options are based on videooculography (VOG) [6] or infrared oculography (IORG) for detecting gesture or eye movements, on infrared head-operated joystick [7] for detecting head movements or even on electrooculographic mouse [8] for displacing a pointer on a screen.

One of the most potentially useful applications for increasing the mobility of disabled and/or elderly persons is wheelchair implementation. A standard motorized 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 because it requires fine control; 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 maneuvers. 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. Many people with severe disabilities usually 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.

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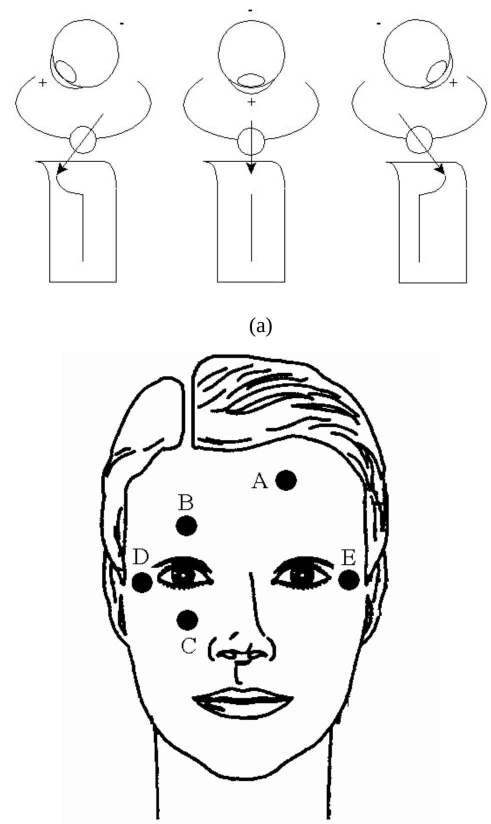
Our goal is to implement a wheelchair guidance system based on electrooculography [9], [10]. This work is included in a general purpose navigational assistant in environments with accessible features to allow a wheelchair to pass. This project is known as SIAMO project [11], [12] where a complete sensory system has been designed made up of ultrasonic, infrared sensors and cameras in order to allow the detection of obstacles, dangerous situations and to generate a map of the environment. The SIAMO prototype has been designed with the aim of being versatile, allowing the incorporation or removal of various services by simple adding or removing the modules involved in each task. The main functional blocks are power and motion controllers, human-machine interface (HMI), environment perception, and navigation and sensory integration. Inside this project, our work is centered in developing a HMI based on electrooculography. Experimental results with users have shown that these demand to interact with the system, making the robotic system semiautonomous rather than completely autonomous. Therefore, our system must allow the users to tell the robot where to move in gross terms and will then carry out that navigational task using common sensical constraints, such as avoiding collision.

This paper has been divided into sections to match the main areas of the research work itself: Section II 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 III proposes an electrooculographic model of the eye for determining the eye position in terms of the recorded EOG. Section IV 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 are given in Section V. Finally, Section VI draws the main conclusions and Section VII points to future research work.

II. EOG

EOG is a method for sensing eye movement and is based on recording the standing corneal-retinal potential arising from hyperpolarizations and depolarizations existing between the cornea and the retina; this is commonly known as an electrooculogram [13]. This potential can be considered as a steady electrical dipole with a negative pole at the fundus and a positive pole at the cornea [see Fig. 1(a)]. 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 behavior 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. Its magnitude varies with time, even when all possible variables are controlled. Most of these biopotentials vary widely among normal patients, even under similar measurement conditions. This means that the variability of the electrooculogram reading depends on many factors that are difficult to 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 [14] various studies were made of the accuracy and precision of the EOG in tracking the eye gaze. To eliminate or minimize these defects, therefore, a considerable effort had to be made in the signal acquisition stage to make sure it is captured with the minimum possible perturbations and then during the study and processing thereof to obtain the best possible results.



(a)

(b)

Fig. 1. (a) Ocular dipole. (b) Electrodes placement.

The electrooculogram (EOG) is captured by five electrodes placed around the eyes, as shown in Fig. 1(b). 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 microvolts 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 artifact 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, to-

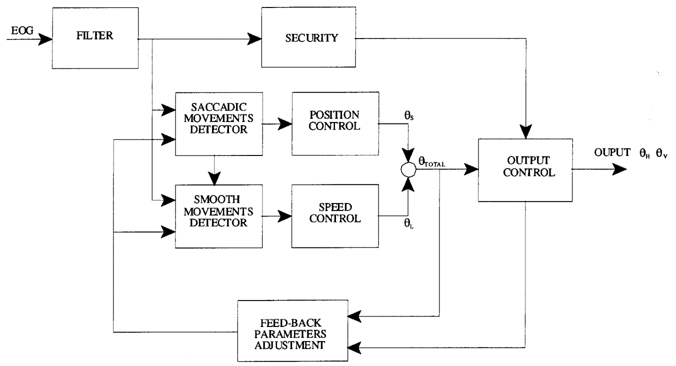
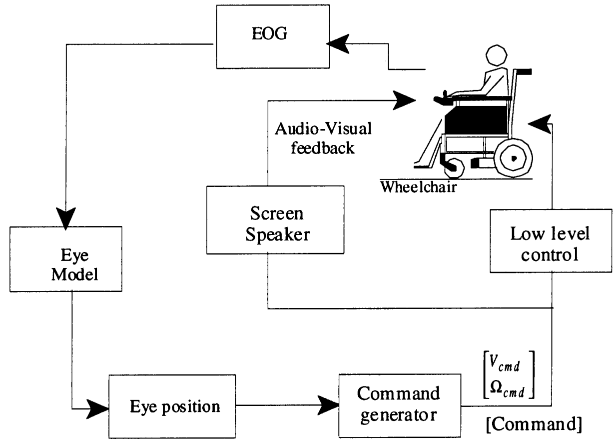


Fig. 2. BiDiM-EOG.



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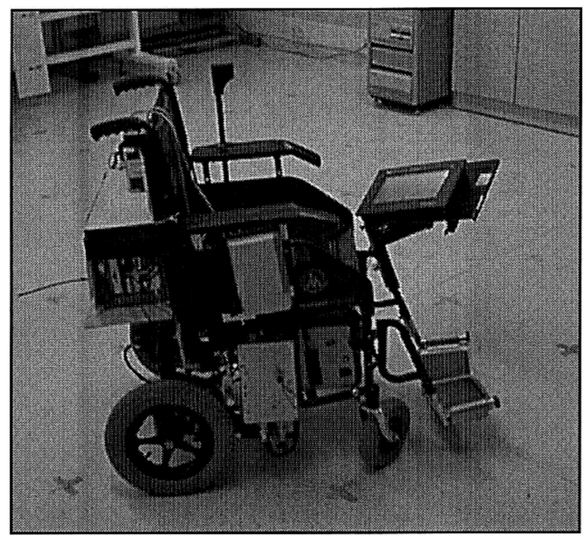


(b)

Fig. 3. Prototype and control scheme. (a) Wheelchair guidance scheme. (b) Wheelchair prototype.

gether with a high pass filter with cutoff frequency at 0.05 Hz and relatively long time constant and a low pass filter with cutoff frequency at 35 Hz. Ag-AgCl floating metal body-surface electrodes are also used.

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

Our aim is to design an electrooculographic eye model capable of obtaining the gaze direction by detecting the eye movements using electrooculography. The oculomotor system is modeled with the eye position within its socket as the output variable, i.e., the eye position with respect to the craneum θo-θcr, although this angle is usually represented by the deviation angles with respect to the eye's central position $\theta_{\text{Horizontal}}$ y θ_{Vertical}. This variable can be obtained by different methods, such as videooculography (VOG) [15], infrared oculography (IOR), scleral coil (SC) [16], etc. In [17] a survey of eye movements recording methods can be seen where the main advantages and drawbacks of each one are described. In this paper, however, it is going to be modeled in terms of the electrooculographic (EOG) signal because it presents a good face access, good accuracy and resolution, great range of eye displacements, works in real time, and is cheap.

In view of the physiology of the oculomotor system, the modeling thereof could be tackled from two main viewpoints: i) Anatomical modeling of the gaze-fixing system, describing the spatial configuration thereof and the ways the visual information is transmitted and processed; ii) modeling of the eye movements, studying the different types of movements, and the way of making them.

On the basis of the physiological and morphological data of the EOG, an EOG-based model of the oculomotor system is proposed (see Fig. 2) (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. After that, 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, 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. Besides, 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.

Several tests prove that the derivative of the electrooculographic signal allows us to determine when a sudden movement is made in the eye gaze and this variation can be easily translated to angles. This technique can be used to help disabled people, since we have obtained an accuracy error of less than $\pm 2°$ and a spatial resolution nearly $\pm 70°$. 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) [18].

IV. Guidance of a Wheelchair Using EOG

The goal of this control system is to guide an autonomous robotic wheelchair using electrooculographic signal generated by eye movements within the socket. Fig. 3 shows the prototype implemented and a diagram of the control system. The EOG signal is recorded by means of Ag-AgCl electrodes and an acquisition card, and this data is sent to an on-board computer in which they are processed to calculate the eye gaze direction or eye movements using the BiDiM-EOG model of the eye. This then serves as the basis for drawing up the control strategy for sending the wheelchair control commands. These commands are sent to a controller that implements the high-level control and generates the linear and angular speed commands of the wheelchair ($[\mathrm{V_{cmd}}\ \Omega_{\mathrm{cmd}}]^{\mathrm{T}}$). The wheelchair's kinematic model then transforms these speeds into angular speeds for each wheel ($[\mathrm{V_{r,cmd}}\ \mathrm{V_{l,cmd}}]^{\mathrm{T}}$) and they are sent to a low-level control module where two close-loop speed controls are implemented. As it can be seen, the system also has an audio-visual feedback, with a tactile screen or laptop positioned in front of the user and a speaker.

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

The wheelchair can be controlled using EOG by various guidance strategies: direct access guidance, guidance by automatic or semiautomatic scanning techniques and guidance by eye commands. In former works [10], we have studied these strategies, nevertheless, the main features are commented of each one of them.

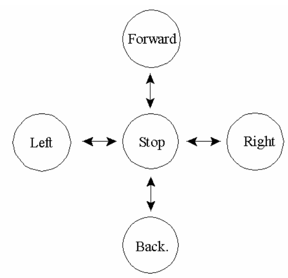
A. Direct Access Guidance

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 (usually by time, although sometimes blink can be used). The drawback of this interface is the Midas Touch problem: the human eye is always ON and therefore, it is always looking somewhere. Everywhere the user looks, another command is activated. This guidance strategy can hence be of use only in supervised applications, since the system does not guarantee the safety of the user when a loss of control happens.

Another drawback of this technique is that the screen showing the interface has to be in front of the user and might thus block 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.

Fig. 4(a) 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.

(a)



(b)

Fig. 4. (a) Direct access interface. (b) State machine using speed fixed per event.

As it 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:

- FORWARD: The robot's linear speed increases (the wheelchair moves forward).
- BACKWARD: The robot's linear speed decreases (the wheelchair moves backward).
- RIGHT: The angular speed increases (the wheelchair moves to the right):
- LEFT: The angular speed decreases (the wheelchair moves to the left).

Wheelchair speed control can be done using a state machine with fixed speed per event [Fig. 4(b)] or proportional speed to state vector. The easier guidance option consists on commands mutually exclusive and speed fixed per event. 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 customized for each user. Another option consists on using proportional speed to state vector. In this way, selecting FORWARD or BACKWARD commands, the linear speed is fixed in each moment, and with RIGHT and LEFT commands the angular speed is fixed. This allows us to make continuous control of the wheelchair. Nevertheless, this type of guidance requires a great precision by the user, and we must keep in mind that small shifts between interface and head position or head movements cause a displacement of the cursor in the screen very difficult to avoid and correct.

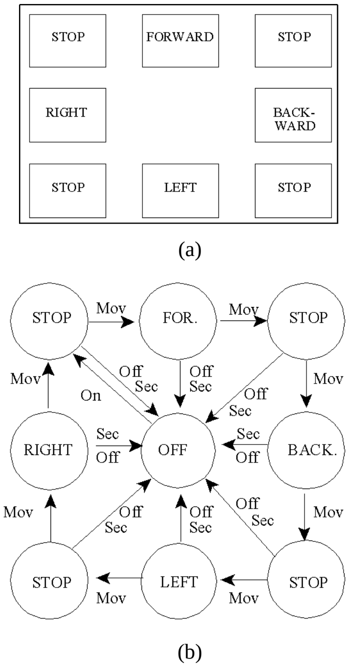


Fig. 5. (a) Interface of scanning guidance. (b) State machine.

B. Scanning Guidance

With this system the user accesses the desired command by scanning all the established guidance commands. The user is presented with a screen showing diverse 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 Fig. 5(a).

As can be seen, the set of commands is small.

STOP:	The robot stays stopped.
FORWARD:	The robot's linear speed increases (the wheelchair moves forward).
BACKWARD:	The robot's linear speed decreases (the wheelchair moves backward).
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 BACKWARD and FORWARD commands, which, besides governing the linear speeds, also establish the wheelchair's direction. The speed commands are integrated into the BACKWARD, FORWARD, RIGHT, and LEFT commands, which generate the corresponding linear and angular speeds adapted to each user.

Command generation is codified by a state machine defining the time-dependent state (command) of the system, as shown in Fig. 5(b). With the semiautomatic guidance strategy, the users themselves 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, it has been opted for time-validation, 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. The command is deactivated when another movement action is executed.

C. Guidance By Eye Commands

One of the most important problems about these interfaces (direct access and scanning access) is that the user has to select a command on a screen. This causes that screen has to be placed in a position where users can see it. For this reason, people with great disabilities (for example, who can not move their head) have great problems for guiding the wheelchair using these techniques, because it is necessary to place the screen in front of their visual map, and therefore, this is reduced. To avoid this problem, the best option is not to use a graphical interface to select the guidance commands, but to establish an ocular movements codification.

However, it is always necessary to establish a feedback about the state of the guidance in each time (in this case, the system has an audio-visual feedback based on a LCD and a loudspeaker) that permits the user to know the command selected in each moment and the state of the guidance.

Therefore, 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.

There are several strategies for coding ocular movements. However, the easiest are: activation-deactivation of commands and continuous control.

Both cases use an interface as shown in Fig. 6(a).

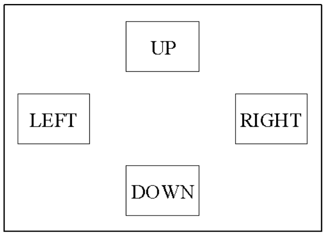
1) Guidance using activation-deactivation of ocular commands: This control consists on detecting some ocular actions and execute an associated guidance command. The guidance commands are effected by means of the following ocular actions:

UP:	The wheelchair moves forward.
DOWN:	The wheelchair moves backward.
RIGHT:	The wheelchair moves to the right.
LEFT:	The wheelchair moves to the left.

As can be seen, speed fixed per event is used. To finish the execution of this command is enough with generating another ocular action (in this case, this ocular action is considered as deactivation command) and the system reaches the rest state.

Fig. 6(b) shows the state machine which codes the command generation and it can be seen the command selected as a function of time and the ocular actions generated.

2) Continuous control by eye commands: This type of control aims to simulate the intuitive control of a nondisabled 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 all the time the angular and linear speeds of the wheelchair. The aforementioned movement



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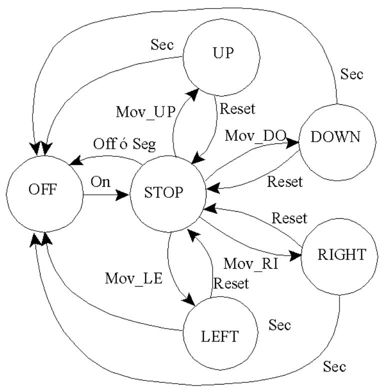

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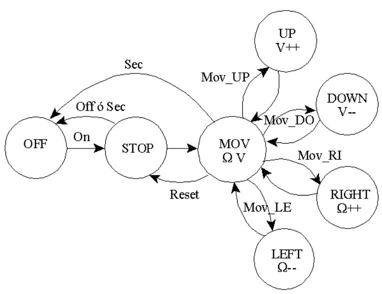

(c)

Fig. 6. (a) Interface of guidance by ocular command. (b) State machine using activation-deactivation. (c) State machine for continuous control.

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–).

Fig. 6(c) shows the state machine for generating commands using this type of guidance. As can be seen, when users look up (Mov_UP) the linear speed increases (V++) and when users look down (Mov_DO) the linear speed decreases (V–). Besides, it exists alarm and stop commands for dangerous situations that permit to stop and switch off the system.

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

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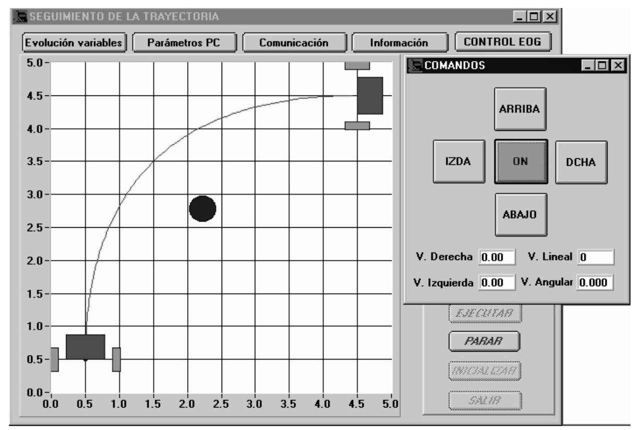


(b)

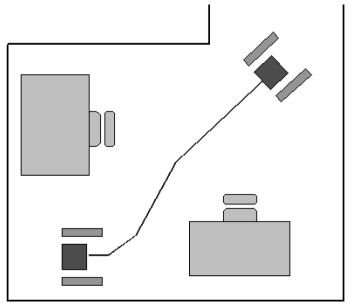
Fig. 7. Example of wheelchair guidance using EOG simulator. (a) User using simulator. (b) Graphical interface.

or change to a state of repose for the robot guidance to be begun again from zero speed.

V. Results of Electrooculographic Guidance

A period of training is necessary to learn to guide a wheelchair by EOG techniques. For this reason a 2-D electrooculographic simulator has been developed. This way, a disabled person trains and learns the operation of the same one and acquires enough skill to guide the prototype. Fig. 7 shows how an user controls it. Its functioning is very simple: first of all, a trajectory is defined introducing the origin (x_{ini}, y_{ini}, θ_{ini}), the destination (x_{end}, y_{end}, θ_{end}) and obstacles, and in an automatic way a possible trajectory is generated. After that, the system allows to configure all guidance parameters (wheelchair parameters, type of guidance selected) and adapt them to the user. During the execution mode, user guides the wheelchair following the trajectory. When the desired goal is reached, the simulator stops and the followed trajectory and the desired one can be observed. The results obtained working with the simulator have shown that disabled people usually require about 10–15 min to learn to use this system.

After the learning process, user can progress to the real guidance of the wheelchair. In this case, the results obtained have shown that users require about other 15 min to acquire enough skill for guiding the prototype [19], [20].



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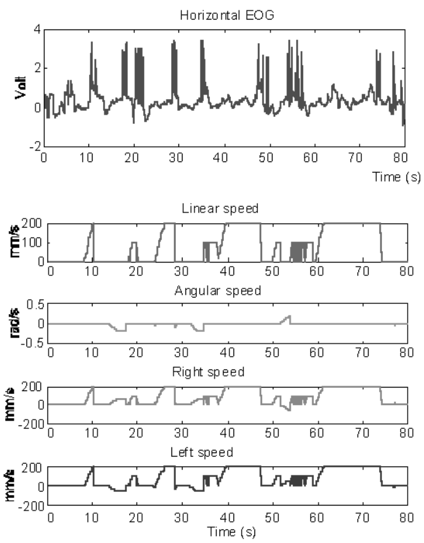

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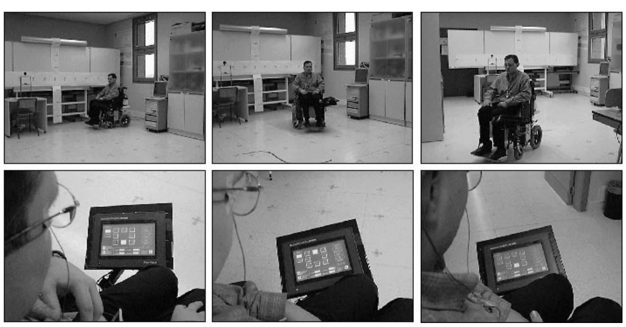
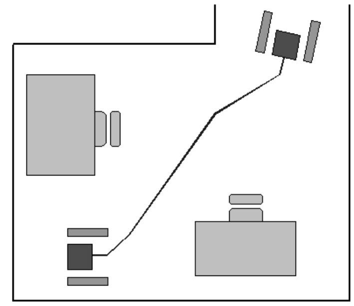


(c)

Fig. 8. Example of semiautomatic scan guidance. (a) Trajectory. (b) EOG signal and wheelchair speeds. (c) Sundry images.

Next, different guidance options to carry out the same trajectory are shown. Fig. 8 shows an example of guidance using semiautomatic scan. It can be observed the trajectory followed Fig.8(a), the EOG signal registered and speeds of the wheelchair Fig.8(b) where it is only necessary the horizontal derivation and a sundry of images of the guidance Fig.8(c). Fig. 9 shows an example of guidance using activation-deactivation of ocular commands. And Fig. 10 gives an example of continuous control by eye commands. In these figures the linear and angular speed of the wheelchair can be observed, as well as the speeds of each wheel in each instant of time in function of the EOG acquired in each moment. The number of ocular actions or carried out ocular movements can also be observed.



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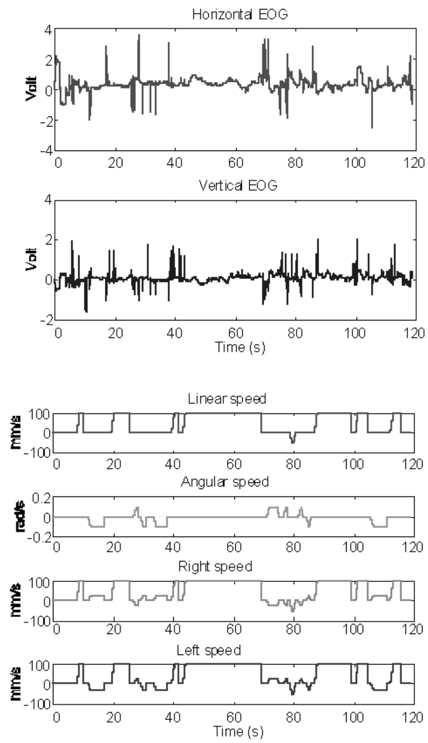


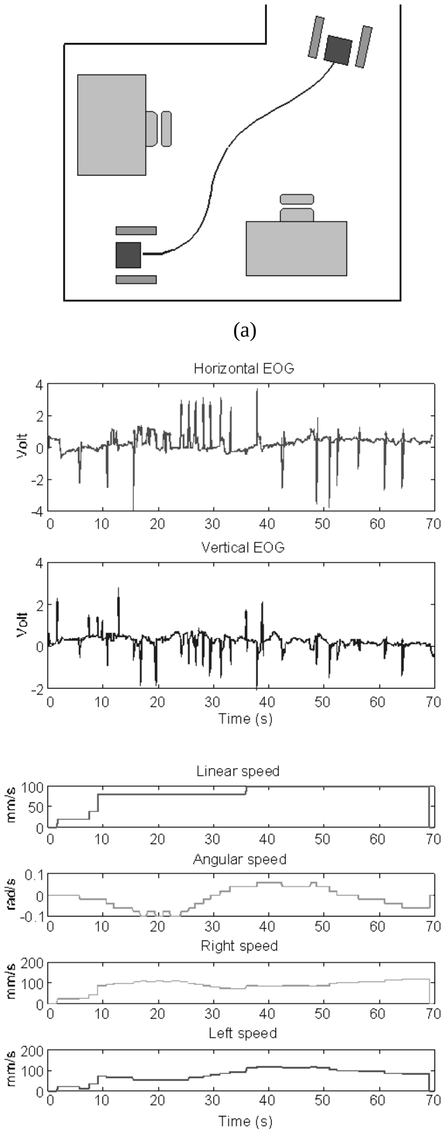
(b)

Fig. 9. Example of guidance based on activation-deactivation of ocular commands. (a) Trajectory. (b) EOG signal and wheelchair speeds.

The wheelchair guidance strategies have been tested by five users that do not present severe disabilities (tetraplegics or similar), although they have different problems of mobility that forces them to walk with a wheelchair which they manage by means of a joystick. Besides, it has been necessary the help of another person to place the electrodes on the face of the users.

Next, the main conclusions about the guidance characteristics using EOG are described.

- The guidance strategy (type of guidance) has to be adapted to the ability of the users. Therefore, the particular needs of the user establish the possible electrooculographic guidance strategies.
- The main guidance factor is the selfconfidence of the users and their ability for guiding the wheelchair and responding to different guidance circumstances. This selfconfidence is great when another person supervises the guidance and avoids dangerous situations.



(b)

Fig. 10. Example of guidance using continuous control by eye commands. (a) Trajectory. (b) EOG signal and wheelchair speeds.

- The interface comfort is very important because it guarantees that EOG guidance would be attractive for the users. Therefore, it will be used the guidance interface more comfortable for the user in function of its ability to do it.
- Comfort is inversely proportional to tiredness, and it depends on the ability of the user for doing the guidance ocular actions and time required for reaching the goal. It can be established that the number of ocular actions to do it is directly proportional to tiredness.
- Another very important factor is comfort for generating the trajectory to reach the goal. In this way, the generation of a trajectory using simple guidance commands (forward, backward, right and left) is more uncomfortable than guidance using continuous control over linear and angular speed of the wheelchair. This is, to use speed fixed per event is more uncomfortable than to use proportional speed to state vector.
- The degree of concentration required to the users influences in their tiredness. Although the degree of concentration depends on the guidance strategy selected, it depends a lot on the ability of the user to control its ocular actions.

A detailed study on the characteristics of the use of the EOG in applications of help to the mobility and in HMI is described in [20].

A comparison can also be observed among EOG and other advanced methods used in the wheelchairs guidance (videooculography and infrared oculography), commenting its advantages and disadvantages. Nevertheless, the results obtained in guidance using a technique or another are similar, although the electrooculography is more uncomfortable in principle to the user since it requires electrodes. However, in function of the type and degree of handicap it is more interesting to use one or other, being observed that if a person presents a good control on its head movements it is more comfortable videooculography, but if the control of the head movements is reduced, the electrooculography can present better results. It should be kept in mind that each person has different qualities and to establish a comparative one among different people cannot be appropriate.

Also enlarging this comparison to the traditional methods (joystick) it is observed that as much as bigger is the degree of freedom and movements that the user can carry out, easier and more comfortable it is the guidance of the wheelchair. This is, a person that can move the hand, the head and the eyes, usually prefers to use the joystick, since he continues having freedom of head movements and eyes.

VI. Conclusion

This work has been developed to provide solutions for particular needs of an important group of disabled and/or elderly by trying to give improvement to assistance to people who cannot securely operate conventional services. 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 paper, we presented a control system that allows the handicapped, especially those with only eye-motor coordination, to control a wheelchair and, in general, to live more independently. Some of the previous wheelchair robotics research has been restricted to a particular location and in many areas of robotics, environmental assumptions can be made that simplify the navigation problem. However, our work is included in the SIAMO project (inside HMI module) that allows wheelchair to be configured with different features, both at the level of guidance strategies (where our work has been focused) and environment capture. Its modularity makes the system well suited to be easily adapted to specific user's needs. Also it has got an appropriate set of different driving modes according to user's capacities and the structure of the environment. This alternative of guidance by EOG has been tested on a wheelchair prototype, and although the results are rather satisfactory, at the present time tests are still being carried out in order to make it the commanding and training simpler.

Different strategies of electrooculographic guidance have been commented (direct access, automatic or semiautomatic scanning, and eye commands), describing their main characteristics, as well as their advantages and inconveniences. A 2-D electrooculographic simulator has been developed for training and acquiring enough skill before to guide the real prototype. Results have demonstrated that users usually require about 10–15 min to learn to use this system. Aalso commented on are the the main conclusions about the kindness of this system to carry out a study with five nonsevere handicapped users. To be concluded, it has carried out a comparative among EOG and others techniques used in the guidance of wheelchair (joystick, videooculography, etc.), where it is observed that as much as bigger is the degree of freedom and movements that the user can carry out, easier and more comfortable it is the guidance of the wheelchair and simpler it is the system preferred by the user. It has been seen that a clear approach doesn't exist to select a technique and other since each handicapped person presents different features and therefore, the user has the "last word" and he should choose that technique that presents better benefits for its needs.

Finally, 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.

VII. Future Work

Our future goals are to develop new systems which allows disabled handle a computer by means an eye-operated mouse based on electrooculography, and on videooculography using a Web cam to reduce costs, because today exists a tendency toward the use of graphical interfaces. Besides, it is necessary to make a detailed study about the kindness of these systems with people with severe disabilities.

Another work line consists on develop a personal robotics aids that serves for guiding indoor, safeguarding and social interaction.

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