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# A Control System for Robots and Wheelchairs: Its Application for People with Severe Motor Disability

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## 1. Introduction

There is a large number of people with disabilities that involve severe reduction of mobility, such as tetraplegia, brain stroke or vascular brain damage. These people usually have great impairments which prevent them from performing their normal daily activities. For our society, this fact means a great effort in cares and specialized attention that, in most cases, involves caregivers assistance dedicated almost exclusively to these patients.

Although only a small part of the disabled population can be included in these types of injuries, trying to solve or minimise the problems associated with severe motor disabilities is an especially difficult challenge for research and development in Rehabilitation Technologies (RT). The Laboratory of Electronics and Bioenginnering (LEB) of the University of Valladolid, to which the article authors belong, has been working since 1995 on the development of practical systems in this field.

Although, currently, it is impossible to find an effective medical solution for these disabilities, the improvement in patients' personal autonomy should be achieved through technical means. This approach focuses, primarily, on two actions based upon:

- The environment. This action consists in modifying the environment to facilitate mobility, interaction with the ambient and communication.
- The patient. In this case, the action consists in developing human-machine interfaces adapted to each type of disability and desired functionality. Additionally, it is necessary to implement the corresponding actuators or systems to be controlled, including prosthetics and orthotics.

As regards the adaptation of the environment, the implemented solutions have relied, primarily, on laws that promote accessibility, applied to architecture and urban planning. Thus, significant improvements were achieved to facilitate, mainly, the mobility of motor disabled people who use wheelchairs. In this regard, the buildings, the infrastructure planning and the public transport services have been especially taken into account. In order to achieve a suitable ambient, authorities subsidise the reforms in private homes where disabled people live, in some countries (Spain, 2006). Note that this first action, based on the transformation of the environment, also benefits a wider scope of population, such as the elderly or other people with milder motor disabilities.

In the case of adapting the environment, the action is mainly reflected in changes made on the urban and architectural physical space and, in any case, on the special furniture required and home automation elements that facilitate automated control of a home. In contrast, the aid techniques based on patients are more diverse as they rely on a multitude of particular applications. In this way, if functionality is will the topic to considered four main areas of work in developing patient-centric devices can be distinguished:

• Mobility
• Interaction with external technical elements.
• Telecare and telemonitoring
• Communication

In all electromechanical and electronic developments, the four work areas need a suitable interface between the patient and the technical means of control. The development of a suitable and customizable adapter is much more difficult in the case of severe motor disabilities, where there is no possibility of utilising the patient's limbs to control simple or standard devices.

The growing interest in all these work fields is established by the appearance of numerous different works and systems designed to make life easier for the user. A particularly interesting example of application is the control of an interface with a computer, since on that computer just about any control application can be developed. This fact allows to understand that the development of a human-machine interface is the core of the problem to be solved. In order for disabled people to function, one of the most studied tasks has been to facilitate the control of personal computers, (Gareth et al, 2000), (Kim, 2002), (Betke et al, 2002), (De Santis & Iacoviello, 2009) and (Barea et al, 2011). In these works different systems are developed to adapt the control of the mouse cursor using, firstly, an infrared pointer system and secondly a face tracking. Other works present as people with disabilities in the upper limbs can control peripherals (Azkoitia, 2007).

Based on the experience of the research group and the systems found in the scientific related literature, it has been determined that the human-machine interfaces developed must meet the following conditions (Maxwell,1995):

• Adaptation to the user. The interface should used, effectively, taking advantage of any remaining capability of the disabled, which depends on the type and degree of disability.
• Correct choice of the remaining capability to be used. It is important to identify which of the various remaining capabilities of the patient is the most adequate to act with the interface.
• Reliability of the interface. The error level in the interpretation of the commands generated by the patients should be minimised. This task is especially important for interfaces to control personal mobility systems, where potential failures may pose a real physical danger to the user.
• Capacity. The interfaces must be capable of generating a sufficient number of different commands to control the external system.
• Speed and computational cost. The human-machine interfaces should be able to work in real-time or with minimum delay.
• Comfort. This item implies easy usability, ergonomics and low proper interaction with other activities that the patient carries out at the same time.
• Cost. The interfaces to control the system must have a reasonable price for the potencial users.

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As much as the work is focused on creating interfaces to control wheelchairs or other type of mobile systems, as robots, there are several papers that review the different existing systems. Their general conclusion is that improvements should be made on the control interfaces and monitoring technologies for automatic navigation (Fehr et al, 2000). The works found in the scientific literature show different approaches to the development of control interfaces in wheelchairs or surveillance robots for severely disabled people. The solutions proposed in the literature can be grouped into the following strategies:

- System based on voice recognition, (Mazo,1995). The operating principle of such interface systems is reduced to the interpretation of a set of predefined voice commands.
- Motion detection systems of the head or the eye, using cameras, (Úbeda et al, 2009) and (Perez et al, 2009). This type of detection systems is based on monitoring the user's face or a part of it. Thus, the movements made by the user are translated into control commands for the device of interest.
- Interfaces based on electromyography (EMG) and electrooculography (EOG) records generated by muscles during voluntary action, (Barea et al, 2002), (Frizera et al, 2006), (Ferreira et al, 2007) and (Freire Bastos et al, 2009). These techniques are based on the acquisition and analysis of electric logs generated by the muscles, which allow us to know the level of muscle activity and the duration thereof. The term EMG is utilised when unspecified muscle signals are used, while EOG indicates that EMG signals around the eye are used. Thus, combining the duration and intensity of the voluntary muscle contractions, various commands can be generated.
- Electroencephalography (EEG)-based interfaces – Brain Computer Interfaces (BCI), (Millán et al, 2004), (Ferreira et al, 2007), (Escolano et al, 2009), (Freire Bastos et al, 2009) and (Iturrate et al, 2009). This means using the signals of brain activity to control the system after processing and coding possible commands. Currently, there are two types of techniques in this category, the invasive and noninvasive (Millán & Carmena, 2010). The invasive strategy implies that the signals are collected inside the brain or, generally, on its surface. The noninvasive approach uses the signals recorded on the surface of the scalp.
- Systems based on the detection of residual muscle movements and not based on the registration of bioelectric signals, (Huo et al, 2008) and (Alonso et al, 2009). This is the kind of system developed in the research group of the authors and that will be explained in detail in this chapter. It is based on coding small residual muscle movements that the patient can perform and on a suitable sensor to detect such actions.
- Interfaces based on the detection of head position using inertial sensors, (Azkoitia, 2007) and (Freire Bastos et al, 2009). In this case, the objective is to detect the position and the movements of the head by placing an external element on it, so that the movement is collected. With this simple mechanism, a light processing system to manage the signals and encode the desired order can be used according to gesture made in each case.
- System based on control by sniffing, (Plotkin et al, 2010). The guidance system is based on the detection of inhalations and exhalations of the use and further processing to code orders according to a preset sequence of inhalations and exhalations.

- Autonomous navigation, (Alonso, 1999), (Levine et al, 1999), (Minguez, et al, 2007), (Angulo et al, 2007) and (Zeng et al, 2008). The autonomous navigation systems perform an automatic guide to the previously chosen destination. Thus, the user only interferes with the system for choosing the final point; it is the system that automatically takes the user to the desired position. The interface chosen, any of the above points, will be used only at the beginning of the operation or if it intends to stop the automatic guide option.

Additionally, hybrid systems that combine self-guided techniques with directed guidance have been developed. Thus, the device intelligently chooses the best possible option for the next move, after the environment analysis, (Hoppenot & Colle, 2002) and (Perrín et al, 2010). In other cases, the system knows different paths and it performs an automatic guidance after the order of destination, (Rebsamen et al, 2006).

For the development of assistance RT elements is of paramount importance, to have the opinion of the recipients of these developments, i.e., persons with disabilities. Therefore, the research group conducted a survey, among the population with severe motor disabilities, concerning the basic features that systems designed to enhance their autonomy and capabilities should have. The results of this study have been taken into account in the LEB works.

The system presented in this chapter is based on sensors capable of detecting winks performed voluntarily by the user. The devices with these interfaces are classified in the fifth group of the types presented above. To carry out this detection, several user interfaces, based mostly in a pair of glasses support have been developed to detect the movement of the skin near the eye. In this area, when there is a wink the orbicularis oculi muscle contractions and extensions produce a movement. The hardware needed for the treatment of signals received is simple, robust, inexpensive, compatible with commercial wheelchairs and implemented by microcontrollers.

This chapter is divided into different sections. Section 2 presents the objectives that the group aim to achieve by the use of the system. Then, section 3 presents and explains the architecture of each of the component parts and the different interfaces developed. Section 4 makes a comparative assessment of the advantages and disadvantages of the proposed solution and those contained in the related scientific literature, after the presentation of the conclusions reached from the interview survey. In addition, an explanation about the protocols and test which has been put into practice with the developed systems is included. Finally, Section 5 details the conclusions reached after the completion of all the work and subsequent analysis.

## 2. Objectives

This chapter presents the basic theoretical aspects of the interfaces and systems adapted to severe motor disabilities, including an extensive reference to the state of the art in this field. In addition, an interface development, especially suitable for this kind of disabilities, and two particular systems which use this interface are presented. These two systems have the aim, on the one hand, to manipulate a robot that acts as a surveillance or telecare device and, on the other hand, to guide an electric wheelchair. Therefore, the following objectives can be defined:

- Presentation of the parameters that an adapted interface to the severe motor disability must achieve.

- Review of related scientific literature to learn about the different approaches carried out by the research community in this field.
- Study the feasibility of assisted systems for the disabled taking into account the views of users.
- Presentation and operating principle of adapted interfaces developed in the research group of the authors.
- Presentation of the structure and principle of operation of two systems that use the adapted interfaces implemented. The first succeeds in establishing a surveillance and telecare system, using a mobile robot equipped with a webcam. The second facilitates patient mobility through the control of a modified electric wheelchair.
- Presentation of the results and experience in the use of the entire system and interfaces. Additionally, there is a discussion about the advantages of the interfaces based on residual voluntary actions of severe motor disabilities and compare its advantages over other systems found in the scientific literature for the same kind of disability.

The developed devices are described with sufficient level detail. Thus, a specialized reader can incorporate different tools and procedures to their own developments.

The comparison that will be made with similar systems will focus, primarily, on the study and adaptation to the parameters defined in the introduction. In addition, it should be noted that the adequacy of systems will be studied in relation to its use in patients with severe motor disabilities, excluding other types of disabilities like sensorial or cognitive ones and their specific needs.

## 3. Implementation

This section describes the working principle of a robot guidance system based on a user interface customized according to severe motor disabled patients. This system has been implemented in two different applications: the first one, a surveillance and telecare system using a mobile robot equipped with a webcam, and the second one, a system for patient mobility through control of a modified electric wheelchair.

The system diagram shown in Figure 1 describes the structure of the application developed for surveillance and telecare. This system includes a customizable interface, a processing module, a transmission channel, a reception module and, finally, the device to be controlled: a robot, an electric wheelchair or another convenient domotic system. A Scribbler robot type that represents the device to be controlled is included.

Throughout this section, each of the parts of the system presented in Figure 1 will be explained in detail. Additionally, other items and adaptations such as an electric wheelchair with a guide system based on an adapted interface joystick control will be described.

### 3.1 Adapted interfaces

The system presented is designed to collect patient information by detecting voluntary winks. Thus, several different adapted interfaces that are explained in detail in this section have been built in. Most of them required an additional support consisting of a pair of glasses and mechanical items for attachment and adjustment of the different sensors. Figure 2 shows three different types of the built interfaces.
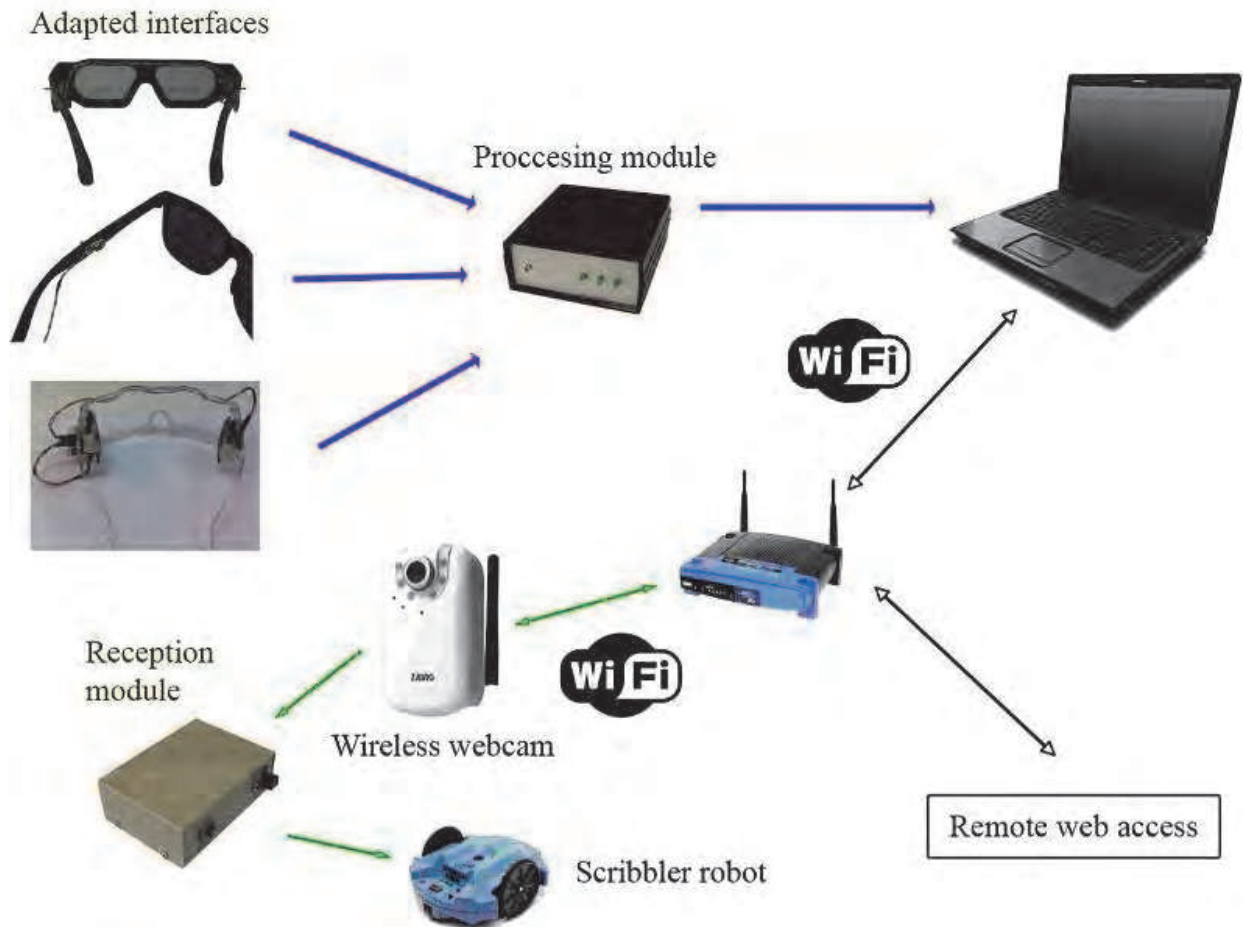
Fig. 1. Diagram of the developed system for telecare and surveillance using a Scribbler robot.

The sensors included in these adapted interfaces and their processing systems are detailed below:

• Optical sensors based on variations of light reflection on the mark that is placed on the skin above the *orbicularis oculi*. In this case, the integrated circuit CNY-70, (Vishay, 2008), has been employed. These devices consist of an infrared LED and a phototransistor whose range of vision is parallel and receives the signal reflected from the facing surface. The use of these sensors requires an additional black and white sticker on the user's skin (see Figure 3). If the sticker is properly placed on the surface of the *orbicularis oculi* muscle, the sensor on the glasses pin will detect the wink because the reflected light changes. This change is registered due to the color change that occurs with the movement of the sticker. Two sets of preprocessing systems for the acquired signals have been built following this screening procedure: the first one based on PIC16F84A microcontroller from Microchip Technology Inc., (Microchip, 2001), and the second based on the Arduino hardware platform that incorporates ATMega microcontrollers from Atmel Corporation, (Arduino, 2009) and (Atmel, 2009).
  The integrated circuit that has been utilised is very simple and only requires two resistors to bias the diode and phototransistor incorporated. The signal generated by the phototransistor is the information signal, and it discriminates a high or low level with the microcontroller.
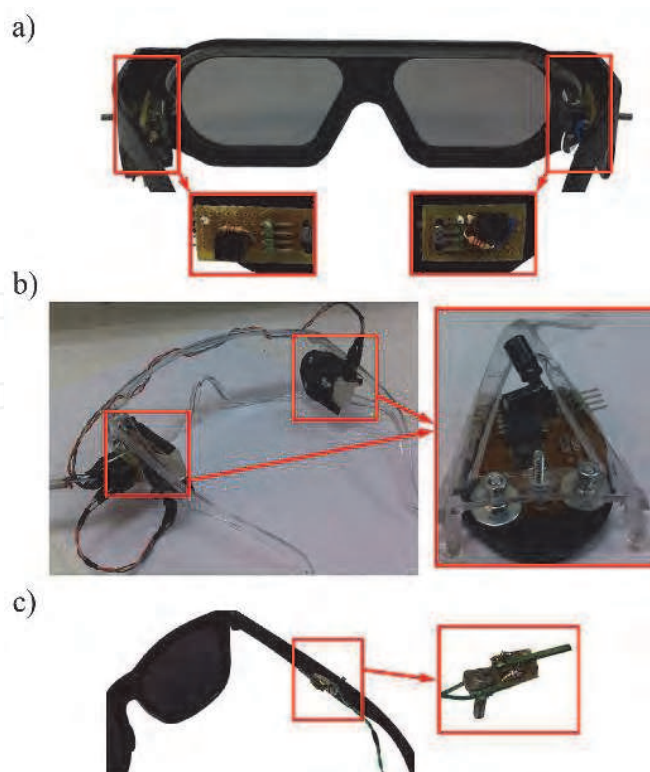
Fig. 2. Three different adapted interfaces built in: a) the highlighted rectangles indicate an optical sensor based on two integrated circuits CNY-70 and their mechanization on glasses. b) the rectangles indicate the circuits fixed on the patient's glasses, built using hardware sensors used in optical mice, c) the highlighted part indicates a customizable interface that uses vibration sensors to detect the winks.

- Optical sensors to detect movements of the *orbicularis oculi* based on optical mice system. Following the same philosophy as the above sensors, these devices are placed on the arm of glasses and detect the movement on the side of the eye. The advantage of this sensor is that it does not need any special attachments, simply placing it on the right place will make it work properly.
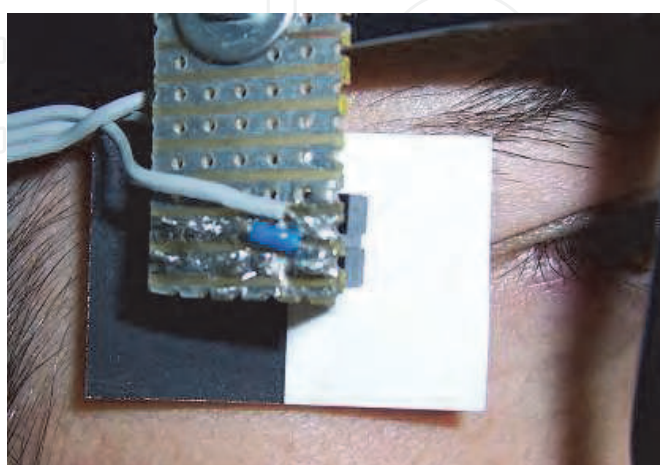


Fig. 3. Adapted interface based on the integrated circuit CNY-70 while it is being utilised by a user. Detail of the sticker on the skin for proper operation.

The sensors only need some parts of the mouse: the integrated optical camera and its peripherals, LED lighting and the light beam guidance prism (see Figure 4).

The system is controlled by the Arduino hardware platform. The interconnection between the optical devices and the platform is achieve through the same signals that a computer processes to detect the movement of the mouse. Thus, it is easy to set different thresholds in order to discriminate motion errors when capturing the information from the user.
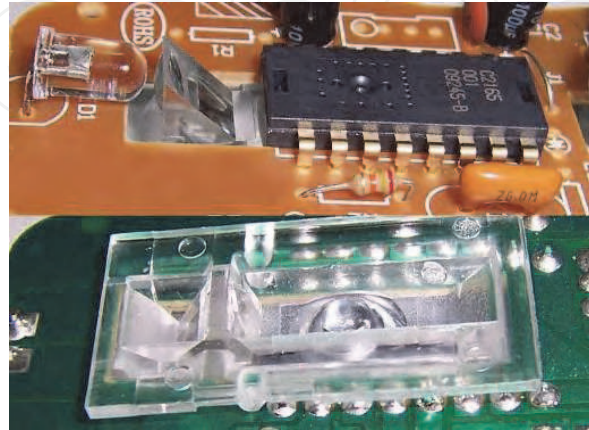


Fig. 4. Detail of the necessary components of the optical mouse for the adapted interface. The top of the image is the top view: LED, prism and integrated camera. The bottom of the image is the bottom view: prism and lens.

- Vibration sensors based on the piezoelectric effect. These sensors have been built in conjunction with a signal conditioner which adapts the signal to a PIC microcontroller, which selects the appropriate orders and discriminates the signals produced by involuntary movements. Again, the philosophy of these sensors is identical to the two mentioned above; it will detect the skin movement near the eye and possible sensor state changes when the eyes wink.

  In contrast with the previous circuits, in this case, the use of a circuit to condition the sensor generated signals is necessary. For this purpose, a simple operational amplifier inverter stage has been developed. This stage is based on the TL082 chip from Texas Instruments, Inc., (Texas, 1999). In addition to this amplifier device, a new stage for information signal pulse discrimination and bounce suppression has been developed. A NE555 integrated circuit from the same company, (Texas, 2002), has been utilised to give shape to this part of the system (see Figure 5).

- Electromyogram electrodes for acquisition of contraction signals of the *orbicularis oculi*. These sensors are based on the acquisition of the bioelectrical signals of each muscle. In this way, it would not be necessary to use the glasses structure interface for signal acquisition, simply, attaching surface electrodes to the skin and an acquisition and processing system, the signal could be obtained and discriminate voluntary winks from other involuntary actions.

  This research group has a high degree of experience in this kind of signals and also has its own neuromuscular training platform UVa-NTS (de la Rosa et al, 2010). This system utilises an amplification and conditioning module (see Figure 6). It consists of different stages: a step for electrostatic discharge, an instrumentation amplifier, a high-pass filter with programmable gain and a low-pass filtering.

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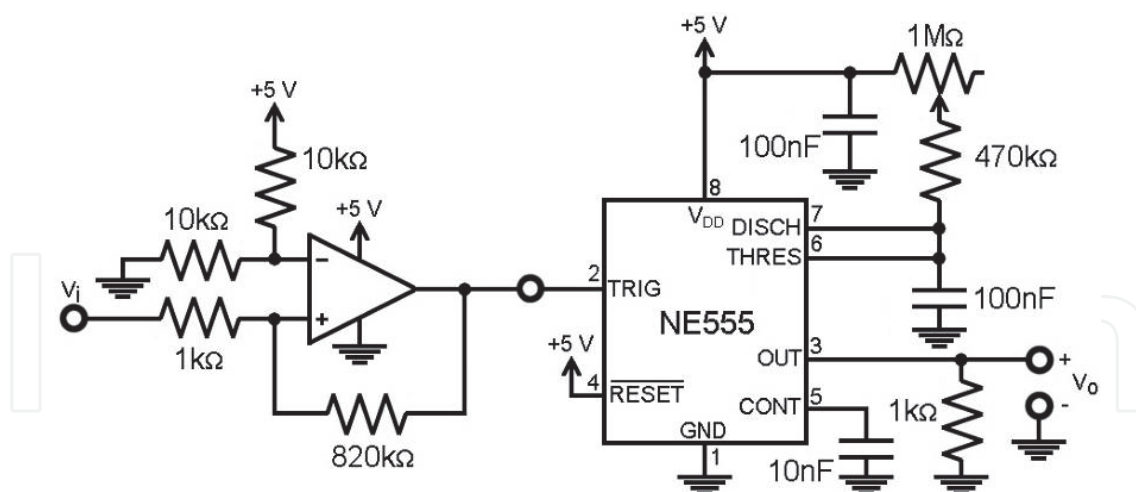Its Application for People with Severe Motor Disability
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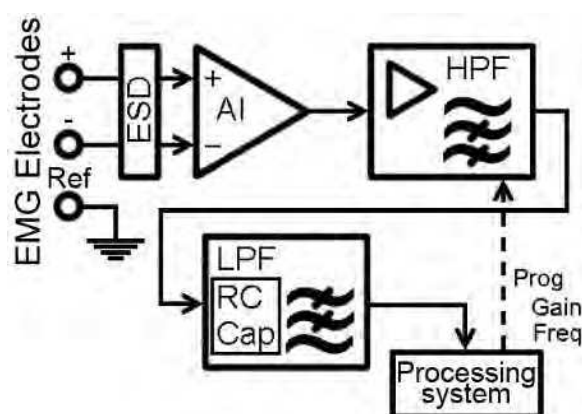Fig. 5. Circuit developed for the adaptation of the vibration sensors output signal.



Fig. 6. Block diagram of the electrodes EMG signals acquisition and conditioning module.

In addition to these systems adapted to control devices by voluntary winks for people with major problems of mobility, a less suitable system has been built. It is an intermediate interface between the adapted one and the hardware processing system:

- Special keypad for disabled people. This keypad consists of four buttons that allow the user to define the same orders as those used in the adapted interface. The problem with this interface is a certain difficulty for the disabled person to control a robot or a wheelchair, as performing simultaneous button presses would be necessary, and the user should have greater flexibility and nimbleness with their hands and fingers.

### 3.2 Processing module

The main task of the implemented processing module is to identify and process the information received by different sensors of the adapted interfaces. This process is straightforward and easily implemented by microcontrollers or hardware platforms such as Arduino.

The processing module is an essential part for the proper functioning of the system and it will be responsible for the discrimination between voluntary or involuntary signal gestures. In addition, the processing system carries out the detection of possible complex orders as the combination of different voluntary signals. The flowchart presented in Figure 7 gives an

idea of the philosophy behind the construction of the processing module and the orders discrimination.
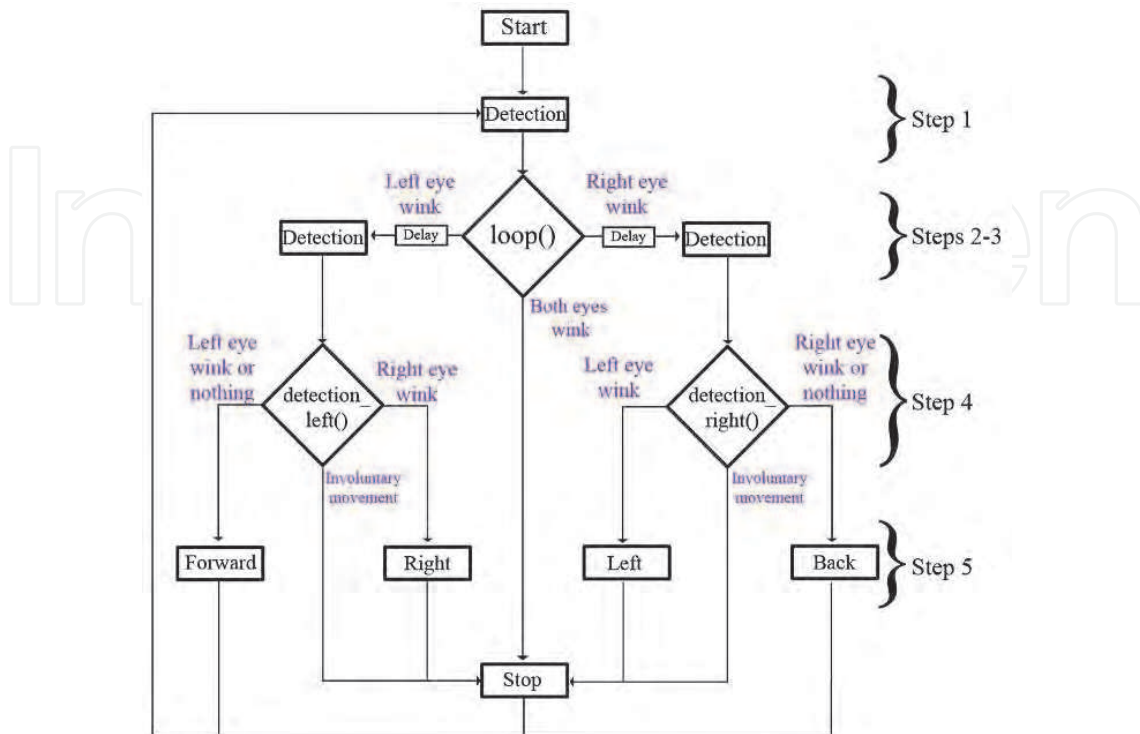


Fig. 7. Flowchart implemented in the processing modules with microcontrollers o hardware platforms.

In a first step, a loop-detection of a possible wink is performed. This initial blink can come from either or both eyes. Once the wink is characterized, the orders are discriminated. On the one hand, if the two eyes wink jointly the robot stop order is activated. Conversely, if the wink is coming from one of the eyes, after a moment's delay, a new similar detection loop to detect a possible new wink is accessed, which discriminates the simple or complex order. The complex commands consist of two consecutive winks made by the two eyes, regardless of the order; in this case, the activated order is 'robot turn right or left and stop'. The simple order consists of a single wink of an eye and it is used to command the movement forward and/or backward of the mobile device.

Following the implementation of this algorithm in the processing module, tests have been carried out with different adapted interfaces, to make sure their reliability and versatility. Switching between interfaces is automatic because the same connector is used. In the specific case of the optical mice-based interface, adapting the code to extract information from the generated sensors signals is necessary.

The received orders are interpreted and forwarded in the appropriate format to a communications device: laptop, notebook or PDA. This device transmits the necessary commands wirelessly to the device to be controlled. In this case, the processing module generates an audio signal of a certain frequency for each of the movements.

### 3.3 Transmission channel and webcams for telecare and surveillance applications

The Wi-Fi is the transmission channel and it is implemented using a router as an access point, allowing both an *ad-hoc* access (computer – webcam) and a remote Internet access. In

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this way, the transmission channel will broadcast a two-way data flow using the video channel to receive images from the webcam and the audio channel to send commands.

Communication is simple for the adapted interface system, through the direct connection with the Wi-Fi device. Thus, the audio orders generated by the processing module are directly received through the communication channel, by the mobile robot with a webcam that has a wireless interface. The control orders are received by the device to be controlled through Internet and the wireless webcam interface. In this case, a router is used as the access point.

On the other hand, if the mobile device needs to be controlled remotely, a simple graphical interface based on a web page, programmed in HTML and JavaScript, has been developed. This graphical interface allows to send the same commands that the adapted one. Operating it is very easy because the screen has five buttons (stop, move forward and backward, turn left and right) that, when pressed with the mouse cursor it sends an audio signal for the execution of the chosen movement.

Hence, with this use of wireless communications and the Internet, both surveillance tasks for disabled people at home and telecare can be conducted. The first application allows the disabled person commanding the robot, with the adapted interface, to observe what occurs in different rooms of the home that he/she cannot reach. Moreover, the second application of remote assistance allows a caregiver, who cannot be physically with the patient, to have control and some information of the status of his/her patient, using the robot and the camera to display the environment of the disabled person.

### 3.4 Reception module and robot

The reception module is responsible for detecting the received order by decoding the information signal from the processing system through the communications channel. The received signal is demodulated to obtain the control command by a system based on Phase-locked loop (PLL). This detection system uses the 74HC4046 integrate circuit from Philips Semiconductor Company, (Philips, 1997), and the LM3914 from National Semiconductor Corp., (National, 1995). The first one, 74HC4046 is a PLL with and integrated voltage-controlled oscilator (VCO), while the sencond is a driver that activates a greater or smaller number of outputs according to an input analog voltage.

Thus, the control input of the LM3914 device is taken from the PLL VCO input and the signal amplitude is directly proportional to the detected frequency of the PLL input and it has been generated by the processing module. The control signal is converted to eight digital signals, where the number of high-voltage signals depends on the input amplitude. For the conversion of these digital signals to the three bits used to encode the commands of the robot, an encoder integrated circuit SN74HC148 Texas Instruments, Inc., (Texas, 2004), has been used. Figure 8 shows a block diagram of this module and the robot.
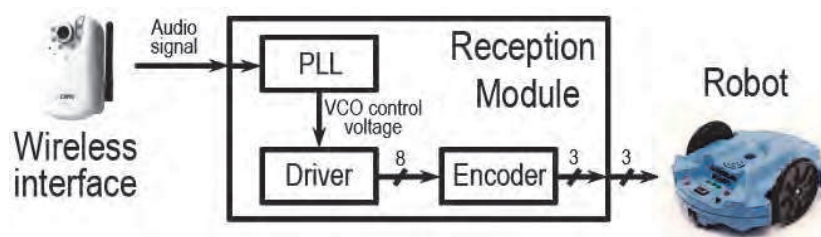


Fig. 8. Block diagram of reception module and robot.

The encoded robot orders, that consist of 3 bits, are summarized in Table 1. The five basic movements -move forward and backward, turn to one side or the other and stop- have been codified through five orders.

| Order | Codification |
|---|---|
| Stop | 000 |
| Move forward | 101 |
| Move backward | 010 |
| Turn right | 001 |
| Turn left | 100 |

Table 1. List of robot control commands and their encoding.

Through this combination of commands, three free combinations can be used for more complex robot movements, such as forward while turning slightly, or habilitate device standby option while controlling another system with the same adapted interface and similar orders.

Apart from other commercial systems such as the Scribbler robot, a robot with a custom design has been used. In the implemented robot, a video surveillance camera is incorporated (see Figure 9). It allows the applications described above, to control all the rooms at home by the disabled person and the caregiver`s remote tasks.

### 3.5 Adaptation to a commercial wheelchair

Once all the system was built and the optimal control of the robot was achieved using the developed interfaces, the equipment was adapted for use in guiding commercial wheelchairs. For this adaptation, a simpler design of the whole system has been implemented. In this design, the processing module is connected directly to the actuator system, the wheelchair. In any case, the amendments to include in the presented system are very easy to carried out.
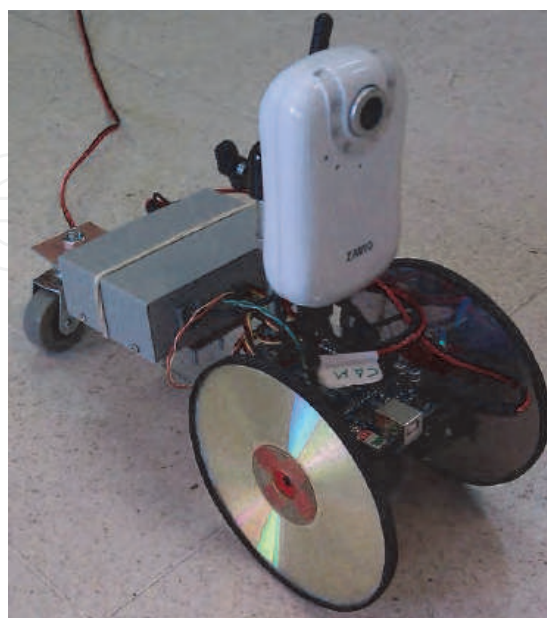
Fig. 9. Custom design robot implemented with the surveillance system.

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The first prototype built for this purpose was intended to replace the control signals generated by the original joystick. Therefore, it could only be used in those wheelchairs which incorporate an identical system: SHARK system with DK-REMA joystick and DK-PMA power module from the Dynamic Controls Company (Dynamic Controls, 2004, 2006). The joystick works easily; it incorporates four fixed coils and a mobile one that moves together with the joystick and induces specific signals in the rest of the coils. The detection of this signals generates the corresponding order for the movement of the wheelchair. With these data, as a result of a reverse engineering process developed, different signals for each type of movement have been generated by the P87LPC769 microcontroller, (Philips, 2002), (Figure 10). This figure shows three signals for each case: the clear line is the reference level, the upper and lower are the order signals and the middle one is the sync signal from the power module.
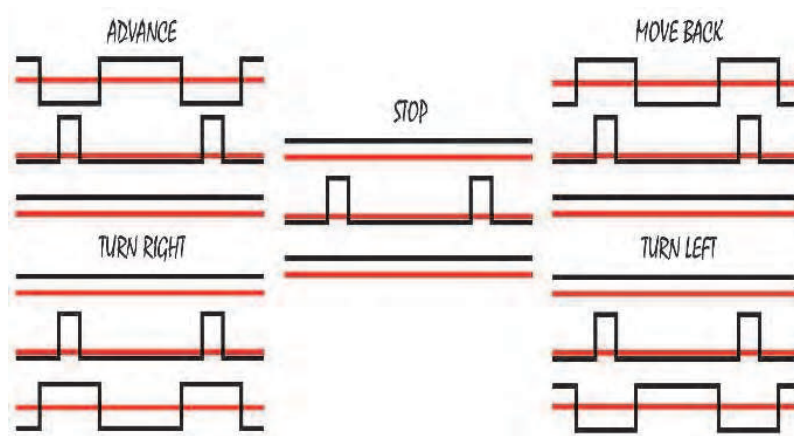


Fig. 10. Signals generated by the microcontroller for the five basic movements of the wheelchair.

These signals are faded directly into the circuit of the joystick, producing the desired movement in each case. The reverse engineering process concluded that the circuitry needed sine signals, but the system worked correctly with square ones because the embedded coils performed filtering functions, and finally, signals similar to sinusoidal ones were obtained. The wheelchair responds appropriately with the synthesized signals and its overall operation is excellent.

In this design, the problem encountered is that it is very delicate to introduce external changes in the internal joystick circuit. These changes can cause a considerable decrease of the device's lifetime. Moreover, the main problem lies in the specificity of the proposed solution, that is, each control system for each wheelchair would require a different model specifically designed.

To solve these two problems encountered when modifying the electronics, a mechanical system based on two 180º rotation servo motors was developed, (Figure 11). This device, controlled by the Arduino platform, is able to move the joystick easily, in every possible direction and ensures universal usability for all wheelchairs that incorporate this kind of guidance system.

Figure 11 shows the prototype built using two 180º servo motors. The joystick is positioned at the bottom of the device. The right image of Figure 11 shows, the top of the prototype, the control Arduino platform, along with a commands LED display and interfaces for

connection: USB to a computer (optional connection), supply jack and RJ11 for the adapted interface. In this image also shows the servo motor responsible for setting the direction in which the joystick will be moved. This servo motor controls a central platform where the second motor is located. On the other hand, the left side of Figure 11 includes the interior view of the joystick control system where the second servo motor is responsible for setting off the final movement and speed by a rod, once the direction is positioned. It also allows the system to go to the rest position, i.e., stop the chair quickly and independent of the direction set firstly. With this system, all the 360º of possible positions for the joystick can be easily reached.
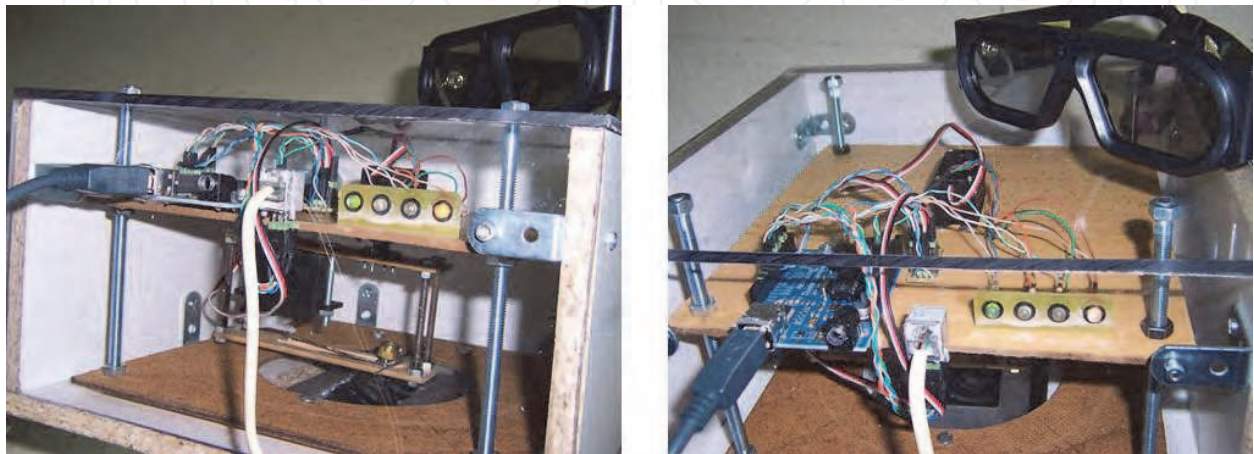


Fig. 11. Wheelchair joystick control prototype based on two servo motors, along with an adapted interface developed.

## 4. Discussion and results

First, there will be a brief analysis of the results obtained from surveys of a sample of the disabled community. The respondents were divided into two groups, face interviews and email consultations. The personal interviews were conducted in the Spinal Cord Injury Association, ASPAYM (Valladolid), and the Agency of Attention and Resources to the Handicapped, CEAPAT (Salamanca). The email consultation was carried out by two virtual network organizations: DISTEC and ListaMedular. Both organizations have been dedicated to the spread of technical assistance devices all over the world and have lots of users.

The statistical study of 40 disabled persons can be summarized to yield some conclusions of interest for guided assistance system designers. The respondents clearly associated these systems to patients with severe motor disabilities. Over 80% of them preferred the guidance systems that are not fully automatic, so that users can have some sort of continuous interaction with them. Finally, over 90% of the sample population declared to be willing to pay the cost of such systems.

Next, the experience gained from the use of the developments dealt with in this chapter will be presented. The LEB has been collaborating for several years with the National Paraplegics Hospital of Toledo (HNPT), putting the systems into practice and testing them. The HNPT is a Spain reference center in this field. This center is, probably, the most appropriate to test the validity of the developments in Rehabilitation Technologies (RT).

Regarding testing in the laboratory, some basic requirements to be met by adapted interfaces as presented in the introduction of the chapter are also rated here. These laboratory studies allow a comparison with other similar systems found in the literature. In relation to the interfaces found for handling external robotic systems, a comparative analysis of their advantages and disadvantages given the above basic requirements will be provided.

- System based on voice recognition (SVR). This type of system has some serious drawbacks. First, the complexity of pattern recognition systems that is neccesary to use. Second, the difficulty of speaking with other people while performing the guidance. Finally, the possibility of interference with environment talks in the control system. The main advantage is the ease of deployment of large numbers of orders.

- Motion detection systems of the head or the eye, using cameras (MDC). They have common problems like the need to install a PC with a camera, the importance of controlling the lighting of the scene and the interference caused by the use of the system during the patient's normal activity (speaking, freedom to look where interested, etc.).

- Interfaces based on EMG and EOG records generated in muscles during voluntary action (IEMGEOG). The problems in these cases are the need for electrodes and to ensure that they maintain a good contact, the need for a PC and the greater complexity of the system. A major advantage is that they can get analog control output, and after proper training the versatility of the device guidance can be improved.

- EEG based interfaces – BCI (BCI). They are very uncomfortable to use and difficult to apply each time they are used. They are slower and less reliable than other methods and, of course, need a PC. Furthermore, the interference is too great for any other activity that the patient is carring out. The advantage of the BCI is the potential to achieve a high level of control, long term, when the serious technical and biological constraints that currently exist can be overcome.

- Systems based on the detection of residual muscle movements and not based on the registration of bioelectric signals (IRMNBS). These are systems with high reliability because they depend on voluntary actions easily detectable with simple sensors. Moreover, the complexity required is low and limited to record the sensors' output. On the other hand, if both the action and the muscle that performs it are chosen properly, the system allows the user great freedom to carry out daily activities. In this case, sensors like the tracking tongue should be excluded because the ability to talk while performing the guidance is affected.

- Interfaces based on the detection of head position using inertial sensors (IHPIS). They are more robust than previous ones and possibly more suitable for marketing. A PC is not necessary but it requires head movements that interfere with the normal activity of the patient.

- System based on control by sniffing (SNIF). Such systems may interfere with the ability to speak while being used. Furthermore, in a situation in which the user breathes with difficulty, due to fatigue or illness, their performance would be affected.

- Autonomous navigation aids for wheelchair users (ANW). It is a good suplement to the above guidance interfaces. These systems are complex and often require installation of some kind of hardware in the environment and in their own wheelchair. They also need the existence of an adapted interface to select the destination. These systems are justified only for extreme cases of immobility and when the subject reaction rate is

incompatible with the dynamic of the guide. In these cases, the only solution is to choose a destination in advance and let the system do the rest.

A summarized comparative analysis between all adapted guidance systems found in the scientific related literature is presented in Table 2. Thus, there has been an evaluation of the parameters presented in the chapter introduction, using six progressive degrees, from very inappropriate (– – –) to very suitable (+ + +).

|          | AU   | CCRC | RI   | C     | SCC   | CF    | CT    |
|----------|------|------|------|-------|-------|-------|-------|
| SVR      | + +  | + +  | +    | + + + | –     | – –   | +     |
| MDC      | + +  | –    | –    | –     | – –   | – –   | – –   |
| IEMGEOG  | + +  | +    | +    | +     | –     | –     | –     |
| BCI      | +    | –    | – –  | –     | – – – | – – – | – –   |
| IRMNBS   | + +  | + +  | +    | +     | + +   | + +   | +     |
| IHPIS    | + +  | +    | +    | –     | + +   | –     | +     |
| SNIF     | ++   | ++   | +    | –     | + +   | – –   | +     |
| ANW      | +    | +    | +    | – –   | – – – | +     | – – – |

Table 2. Comparative analysis between the adapted system interfaces found in the literature and the parameters presented in the introduction. Abbreviations for each of the systems and the parameters have been used. Thus, for columns: AU (adaptation to the user), CCRC (correct choice of the remaining capability to be used), RI (reliability of the interface), C (capacity), SCC (speed and computational cost), CF (comfort) and CT (cost); for rows: SVR (System based on voice recognition), MDC (Motion detection systems of the head or the eye, using cameras), IEMGEOG (interfaces based on EMG and EOG records generated by muscles during voluntary action), BCI (EEG-based interfaces – BCI), IRMNBS (systems based on the detection of residual muscle movements and not based on the registration of bioelectric signals), IHPIS (interfaces based on the detection of head position using inertial sensors), SNIF (system based on control by sniffing) and ANW (autonomous navigation aids for wheelchair users).

Taking into account the previous disccussion and the type of disability to which the developments are directed, the LEB chose the most appropriate option to carry out the adapted interfaces. The system presented in this chapter is based on sensors capable of detecting winks performed voluntarily by the user (a particular IRMNBS system). The hardware needed for the treatment of signals received is simple, robust, inexpensive, compatible with commercial wheelchairs and implemented by microcontrollers. The main advantages of this system are listed below:

• Simplicity of the hardware.
• Light software implemented on microcontrollers.
• More reliable than other systems.
• Low cost and easy adaptation to different wheelchair models.
• Minimal interference with patient daily activities. The necessary conventional biological flashes are not detected, as it should. The winks that activate the system need not be as intense as for having to close the eyes, in order not to lose sight at any time, due to the interface.

The results obtained from practical trials of the devices have responded to the expectations of reliability, speed and convenience for the user. The tests performed with the robotic

system monitoring and telecare have been successful in the controlled environment of the LEB, (Figure 12). Additionally, the trials were prepared in private homes equipped with an Internet connection with a Wi-Fi router.



Fig. 12. Control subjects putting into practice the surveillance and telecare system trials.

Regarding the direct control of the electric wheelchair with the adapted interface developed, the data were collected from control subjects, Figure 13, pending further trials in the HNPT research center. In this case, indeed, it is not important that the subjects who test the system are disabled, since the residual capability used to control the adapted interface, i.e., the eye winks, is similar in both populations.

The trials consisted of training and two definitive tests that indicate the progression of learning. Tests are based on a predetermined circuit, Figure 14, and the complete protocol is summarized as follows:

- Previous 5 minutes free training.
- First test scoring errors and the time to complete the circuit.
- 5 minutes training after a break.
- Second test with new errors and time registration.



Fig. 13. Control subject testing the adapted wheelchair control system.

The conditions for conducting the trial are based on an optimized circuit for an estimated duration of one minute. For safety reasons, for the users without prior training, the circuit did not contain physical barriers. The recorded values can make an assessment of the usability of the system, user satisfaction and speed of learning.
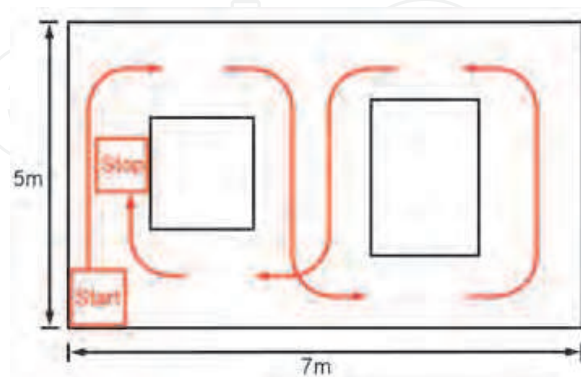


Fig. 14. Designed test circuit for both surveillance and telecare system and adapted wheelchair mobility.

Both systems showed an annoying delay in the response for the action ordered by the user through the interface. This effect is caused by how the interpreting the control commands

has been programmed on the microcontroller. This delay was introduced to facilitate beginners to execute the commands performed by a successive wink of each eye. However, this is not a serious problem, since it is simple to modify the code to speed up the response. In this case, the functioning mode would be customized for users who have been properly trained.

## 5. Conclusions

The design and development of human-machine interfaces for people with severe motor disabilities are activities of great interest to improve the quality of life and independence of such persons. The use of adapted interfaces to their residual abilities serves the disabled to train their remaining capabilities and also provides an assessment tool of the patients for medical specialists.

In this chapter, a brief collection of techniques and interfaces developed by different researchers for this type of patients has been made. The interfaces are generally used to manage domotics and robotic elements with different functions such as mobility, environment control and communication. In the introduction, some basic requirements that the very low mobility disabled-interfaces should meet have been defined. Such requirements can be used to assess the goodness of a given interface or to compare different human-machine interfaces. The control interfaces based on slight voluntary actions, such as winks, are worthy of a high score because they meet most of the conditions.

Once the human-machine interface is developed, a control for two different robotic systems, with good results of satisfaction for users, has been applied. Both systems have been described with sufficient detail to be implemented by those readers with appropriate technical training. The first of these systems -environment surveillance and telecare of the patient system- can be easily modified to use their two-way audio channel, and thus can also perform the communication function. The second system -a mobility system developed- is based on the control of a conventional electric wheelchair, for which only a cheap adaptation between the joystick and the interface of winks is needed. This circumstance significantly increases the accessibility of the system for patients. Both systems can be programmed for a faster response, as users are learning to manage the interface.

## 6. Acknowledgments

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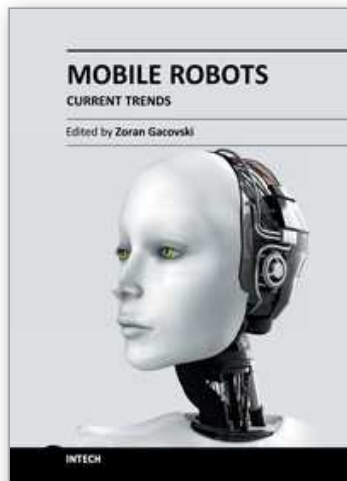
**Mobile Robots - Current Trends**

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This book consists of 18 chapters divided in four sections: Robots for Educational Purposes, Health-Care and Medical Robots, Hardware - State of the Art, and Localization and Navigation. In the first section, there are four chapters covering autonomous mobile robot Emmy III, KCLBOT - mobile nonholonomic robot, and general overview of educational mobile robots. In the second section, the following themes are covered: walking support robots, control system for wheelchairs, leg-wheel mechanism as a mobile platform, micro mobile robot for abdominal use, and the influence of the robot size in the psychological treatment. In the third section, there are chapters about I2C bus system, vertical displacement service robots, quadruped robots - kinematics and dynamics model and Epi.q (hybrid) robots. Finally, in the last section, the following topics are covered: skid-steered vehicles, robotic exploration (new place recognition), omnidirectional mobile robots, ball-wheel mobile robots, and planetary wheeled mobile robots.

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