An Integral System for Assisted Mobility

The Modularity of the Electronic Guidance Systems of the SIAMO Wheelchair Allows for User-Specific Adaptability Based on Environment and Degree of Handicap

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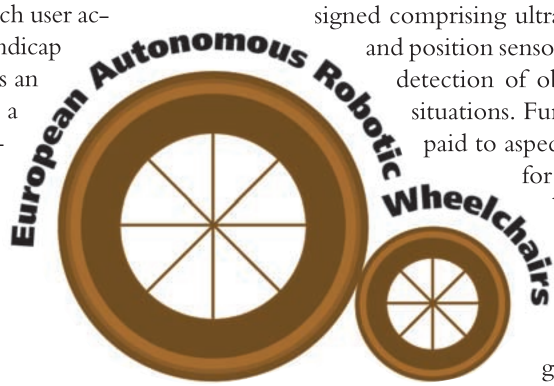
This article presents the SIAMO (Spanish acronym for Integral System for Assisted Mobility) project, a work carried out in the field of electronic systems for the guidance of autonomous wheelchairs as an assistance device for the disabled or the elderly. These electronic systems have been designed to meet a wide range of needs experienced by users of this type of wheelchair. One of the most important features is modularity, making the systems adaptable to the particular needs of each user according to the type and degree of handicap involved. The overall system includes an innovative user-machine interface, a complete sensory subsystem (ultrasonic, infrared, vision, etc), and an advanced strategy of control and navigation. This allows different alternatives for guidance and guarantees user safety and comfort.



Project Overview

The SIAMO project began at the end of 1996 as a continuation of a previous project financed by the ONCE Foundation (National Organization for the Blind of Spain). The result of this first project was a wheelchair prototype in which the electronic system was entirely developed by the research team of the Electronics Department of the University of Alcalá. This electronic system included control of motors and drivers (low-level control), control at the trajectory-generation level (high-level control), user-chair interfaces based on oral commands (isolated words with a user-dependent engine), a joystick, and a sensory system composed of ultrasonic and infrared sensors that allowed the detection of obstacles and abrupt unevenness (such as stairs, etc.) [1, 2].

In order to achieve the objectives presented in the SIAMO project, special attention was given to the human-machine interface (HMI) between the user and the chair. This is the element that most challenges the user's ability to drive the chair [3-5]. It is necessary that users feel that they are in control of the chair at all times. It should also be guaranteed that despite the degree of autonomy, the user can react if any type of problem arises that may represent a risk. Overall, it is necessary that the chair inspires confidence in the user.

That is why safety and comfort have also been important aspects of the SIAMO project. A sensory system has been designed comprising ultrasonic and infrared sensors, cameras, and position sensor device (PSDs), in order to allow the detection of obstacles, holes, and other dangerous situations. Furthermore, special attention has been paid to aspects such as flexibility and modularity, for which a distributed architecture has been designed [3, 4, 6], so the electronic system can be configured according to each user's needs, depending on the user's type and degree of disability. Modularity guarantees independence from both hardware and software points of view, as well as among the different blocks that make up the system. Interest in modularity is also justified because it makes future commercialization of final products easier, allowing module manufacturers to offer users different versions of wheelchairs quickly adapted to any specific need.

System Architecture

The SIAMO prototype has been designed with the aim of being versatile [7]. Therefore, it allows the incorporation or removal of various services by simply adding or removing the modules involved in each task. Main functional blocks are a) power and motion controllers, b)HMI, c) environment perception, and d) navigation and sensory integration.

Figure 1 provides an overall view of the SIAMO project. Three large blocks are included: environment perception and

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integration, navigation and control, and HMI. In the HMI block, there are five guidance alternatives: breath-expulsion driving, user-dependent isolated word recognition, head movements, electro-oculographic signals (EOG), and an intelligent joystick with preprogrammed behaviors if necessary. The sensory system has ultrasonics, passive and active vision (camera and laser diode), infrared (PSD, position sensor device), and low-level safety (bumpers). Depending on the user's needs and the characteristics of the environment [8], the wheelchair may have different configurations. This is possible since each functional block of the SIAMO wheelchair is made up of several subsystems, some of which implement basic functions while other optional ones extend, adapt, or change them. For example, the user-machine interface function can be equipped with or without a display, depending on user demands. The type and number of modules fitted, suitably reprogrammed, define the facilities of the system, the latter being adaptable to the particular needs of each user. In its basic configuration, the SIAMO system needs only the low-level control modules and the simplest user-machine interface, a linear joystick, to work like a standard powered wheelchair.

Communication among different modules of the system, outside or even inside each functional block, is done through a serial bus. Other European workgroups (CALL Centre [3, 9], OMNI team [4], and TetraNauta [10]) have taken the same solution adopting serial buses in their developments. Also, the M3S specification is a notable attempt to achieve an applicable standard for wheelchair electronics systems [6, 11].

The workgroup of the University of Alcalá, in order to give a solution to this architectural problem, decided to use the LonWorks Network fieldbus system. A noteworthy feature of LonWorks networks is their broad application to building automation (at the present time, more than 5 million nodes have been installed in the USA), thereby facilitating and simplifying the interaction between the wheelchair and its immediate environment.

Human-Machine Interface (HMI)

The exchange of commands (HMI outputs in Fig. 1) and state information (HMI inputs) between wheelchair and user is personalized in accordance with the particular needs of the user and the facilities of the fitted system.

Standard interface devices, such as joystick or scanners, have been tried and can be easily added or removed thanks to the open architecture of the SIAMO system. Nevertheless, the more interesting features of the user-machine interface are those oriented to give real driving capabilities to severe

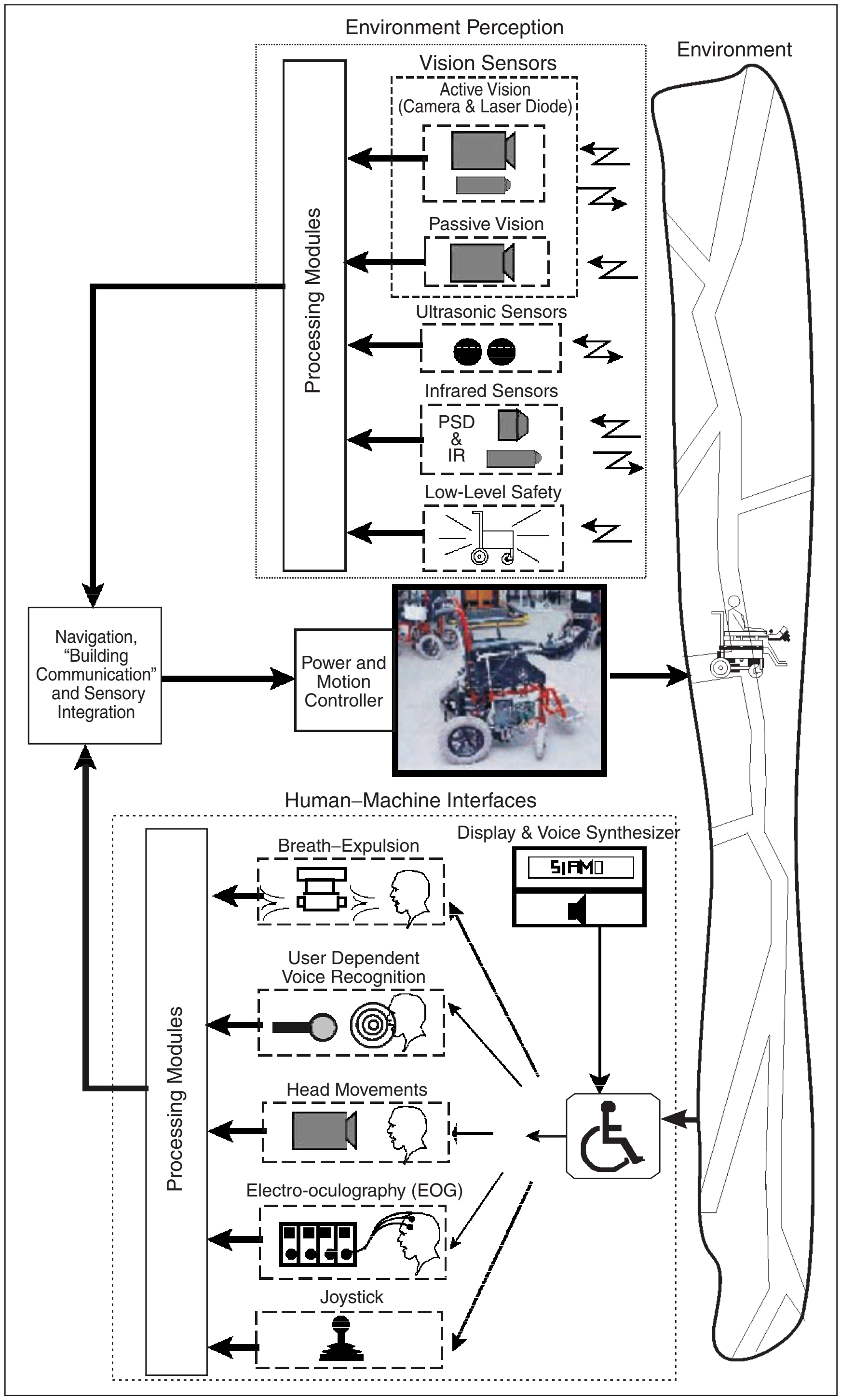

Fig. 1. Overall view of the SIAMO project.

handicapped people who cannot easily drive other conventional devices.

For inputting orders, the user of SIAMO has the following alternatives: linear joystick, discrete joystick, varied buttons or switches, a novel breath-expulsion device, vocal commands, and eye or head movements. It should also be stressed that all the inputting methods, including the linear joystick, have a programmable controller, so it is possible to have both semiautomatic and automatic command modes.

The exchange of commands and state information between wheelchair and user is personalized in accordance with the particular needs of the user and the facilities of the fitted system.

The state of the wheelchair and the feedback of orders reach the user by different ways. This information can be relayed visually or acoustically. Some of the output modules designed are LED indicators for scanners, LCD display of 2 ×16 characters, a graphic high-resolution and high-intensity EL display, and a voice synthesizer.

Guidance by Breath Expulsion

Breath-expulsion units can be found as interfaces for tetraplegics but usually as another way to activate a switch in "scanners" systems that work as follows: an output device (like an array of LEDs) changes a pattern in a cyclic way and the user activates the one desired by means of a simple action, such as blowing over a pressure switch.

The one designed in the SIAMO system works in a very different way: as an "almost-real-time" driving unit. A differential air-flow sensor with a linear output is used (Fig. 2), so it is possible to detect both strength and direction of breathing. The output of such a sensor is processed, and as a result codified commands are sent to the navigation modules. With an "easy-to-use" breath code it is possible to obtain the references of linear and angular velocities and to stop the chair in case of trouble. This driving aid allows commanding the chair in broad corridors and halls as well as crossing through doors of 1.5 m wide without any other assistance or sensory system.

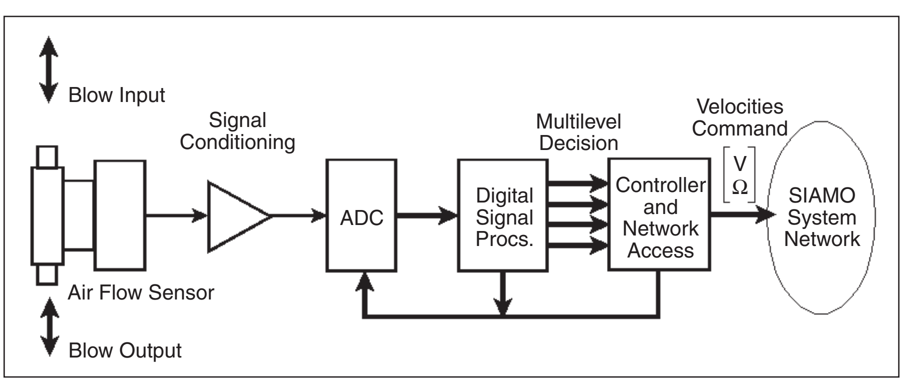

Fig. 2. Block diagram of the breath-expulsion unit.

Guidance by Head Movements

The objective of this alternative is to guide the wheelchair by means of codification of the user's head movements. The general architecture for this solution is shown in Fig. 3. As can be seen, a visual feedback system is implemented in which the guidance references are introduced by the user by means of head movements.

A CCD color micro-camera, placed in front of the user, acquires face images. To locate the head in the image, an original skin-color segmentation algorithm has been used, called the "Unsupervised and Adaptive Skin Gaussian Model" [12, 13]. This method segments any person's skin, even of different races, under changing light conditions and random backgrounds. To do this, a stochastic adaptive model of skin colors in a normalized RG color space has been used.

The model is initialized by a clustering process. This divides the chromaticities of an image in a number of classes (k) between one and a maximum value (K). At each step, the k cluster centers are estimated using an approximate color histogram. These centers are adjusted using a competitive learning strategy in a closest center sense. Finally, a clustering quality factor is calculated for each topology. The process is repeated, adding a new cluster center in each step until the maximum number of classes is reached. The maximum quality factor gives the number of classes that best fits the histogram. With this number of classes the skin cluster is located depending on the distance between the center of the clusters and a master skin color position. Then, the skin class is modeled by a Gaussian function and the parameters of the model are adapted by a linear combination of the known ones using the maximum likelihood criterion.

Estimated state vectors and their derivatives are introduced in a command generation state machine. Each state codifies one of the following commands: turn right, turn left, increase speed, decrease speed, and idle. State transitions of the machine are achieved by analyzing the activation of some fuzzy conditions of input variables, based on thresholds. Commands are sent to another state machine that implements the high-level control and generates linear and angular speed commands to the wheelchair (V, Ω), as a function of time.

A visual feedback loop is closed by the user as the user reacts according to current circumstances. For instance, if the system detects a right-turn command, the wheelchair will turn to the right until the command finishes.

Guidance by Electro-Oculography

For those who cannot even move their head, there is another guidance alternative: to guide the wheelchair using the position of the eye into its orbit. This is done by means of an electro-oculographic (EOG) signal. Multiple options can be used to control the wheelchair movements: interpretation of different commands generated by means of eye movements, generation of different trajectories in function-of-gaze points, etc [14]. In our case, the first option has been implemented because it allows one to generate simpler code for controlling the wheelchair using eye placement.

Analog signals from the oculographic measurements have been turned into signals suitable for control purposes. The derivation of the EOG is achieved by placing several electrodes: two on the outerside of the eyes to detect horizontal movement and another pair above and another pair below the right eye to detect vertical movement; and a reference electrode placed on the forehead. Figure 4 shows their location.

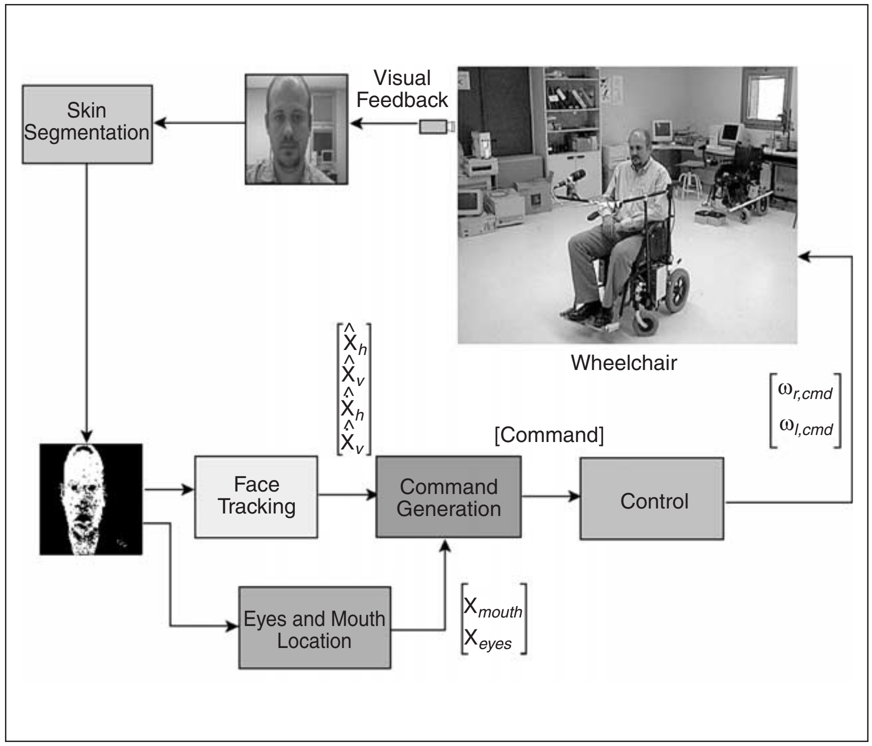

Fig. 3. *Architecture of guidance by head movements.*

The electrodes placed around the eyes measure the EOG potential [15]. This potential is a function of the position of the eye relative to the head. The EOG signal changes approximately 20 μV for each degree of eye movement. Signals are sampled 10 times per second. The electrodes used are reusable Ag-AgCl biopotential skin electrodes, and gel is used as electrolyte.

The processing of the EOG signal has several problems; the main one is that this signal is seldom deterministic, even for the same person in different experiments. The EOG signal is the result of several factors, including eyeball rotation and movement, head and eyelid movement, electrodes placement, influence of the illumination, etc. For these reasons, it is necessary to eliminate the shifting resting potential (mean value) because its changes in time. A software program has also been developed in order to calibrate eye position.

Guidance by Voice Commands

Another interesting way of driving is using voice commands; this can be useful at both low-level and high-level commanding. It is not necessary to have a computer with a voice recognition tool to carry on this task. In the voice-commanding system designed in the SIAMO project, a commercial isolated word recognition chip has been used [16]. Inside that chip there is an analog processor that consists of a preamplifier and a bandpass filter with cut-off frequencies of 100 Hz and 4 kHz. The output signal of the analog stage is digitally processed with the objective of enhancing the useful information of the voice signal. Using directional microphones, a 95% success rate is achieved even in high noise level environments.

A set of only nine voice commands has been included to simplify the use of the wheelchair [2]. These commands have to be chosen by the user and recorded on a personal card memory. Each command has an associated driving function: Stop, Forward, Back, Left, Right, Plus, Minus, Password, and Track. Starting from a halted state ($V = 0$, $\Omega = 0$), commands such as "Forward," "Back," "Left," "Right," give V or Ω speed a fixed initial value, positive or negative, according to the case. Then the "Plus" and "Minus" commands increase or decrease speed up to certain pre-arranged limits.

The "Password" command when pronounced once stops the recognition process and the movement of the wheelchair itself. This enables the user to have a conversation in which those words having a control function assigned may appear with the only exception of the control word "Password."

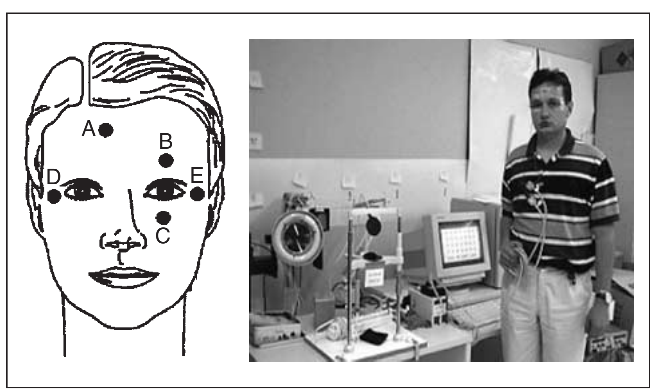

Fig. 4. *Electrodes placement.*

When pronounced again, it returns to the previous control. The "Track" command allows switching between "Voice Control" and "Autonomous Control" modes.

The voice recognition system includes three operation modes, selected by the user: training mode, recognition mode, and pattern transference (between personal card and local RAM mode).

Sensory System

Detection of the environment is essential, both from the point of view of safety (to avoid collisions and falls) and of tracking (to allow positioning and following of predefined paths). As already shown in Fig. 1, the lowest level is made up with simple bumpers and contact detectors activated by situations of imminent collision. At a higher level, the sensory system is built up with a full set of intelligent devices that are able to both recover environment information and to preprocess the raw data. This is done by grouping several sensors in modules that will be interconnected to the whole system through a serial link. As the sensory information has been already processed, data traffic is decreased and sensory information is more reliable.

Some of the modules designed and tested are ultrasonic and infrared sensors, as primary obstacle detectors; an active vision system that measures range data based on a laser emitter diode; and a passive vision system, based on artificial landmarks oriented to environment recognition and navigation tasks. Main features of these modules will be described in the following paragraphs.

Ultrasonic Subsystem

Ultrasonic devices are widely used in mobile robots, with the most common type a ring-shaped distribution mounted around the structure of the mobile unit. A significant feature of this type of system is the independence in action of each of the transducers. The number of transducers to be used depends on their angular aperture, the area to be covered, and the lateral resolution required. When talking about the type of transducer, the electrostatic one predominates, but if the number of these is high it will lead to "overloaded" installations because of the large diameter (4 or 5 cm) of this type of transducer

The design of the ultrasonic module for the wheelchair, from which all the hardware has been developed, covers everything from the power stage to excite the ultrasonic transducers to the control unit. Each module is divided in several stages

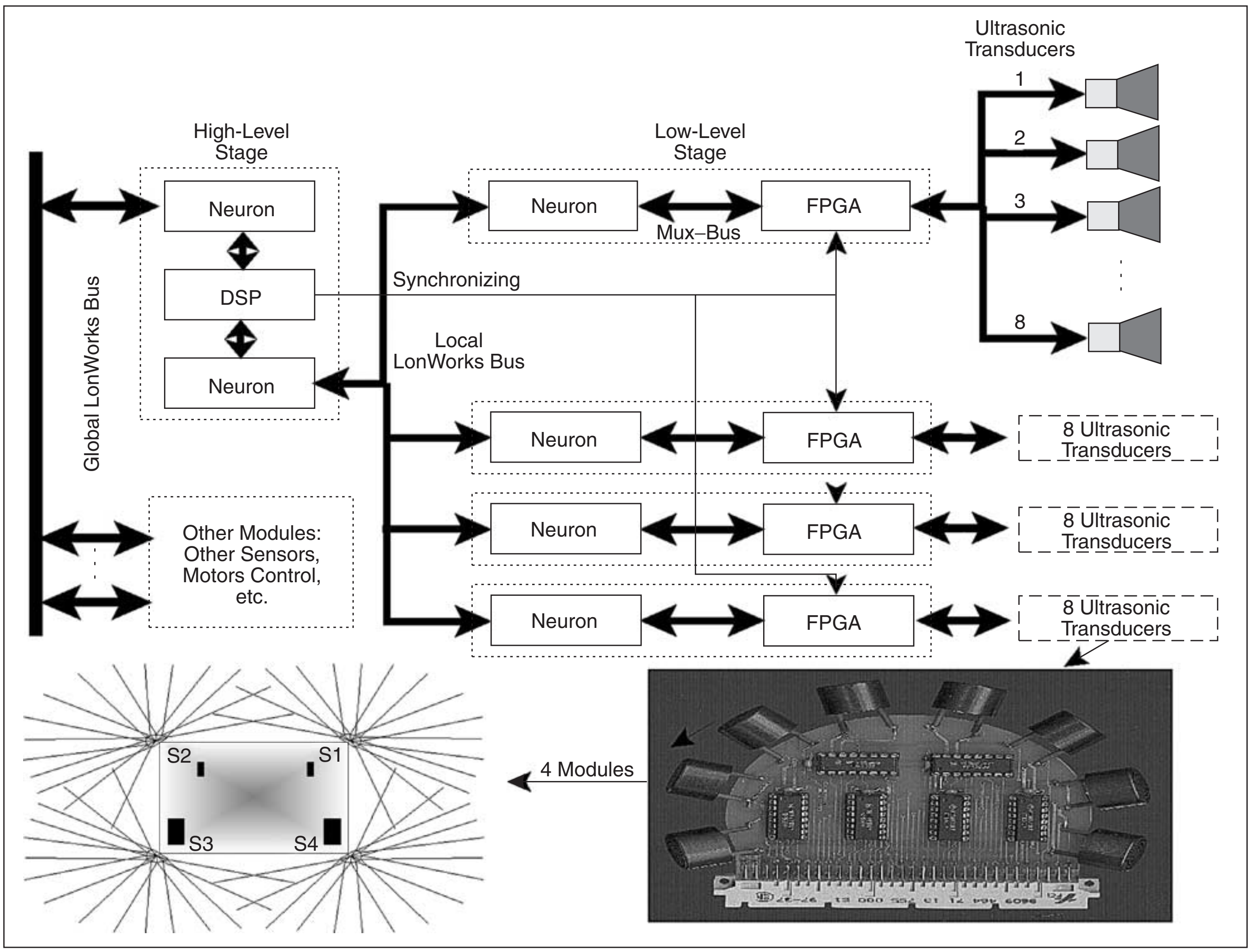

Fig. 5. *Block diagram of the ultrasonic system.*

(Fig. 5). A low-level stage controls sets of eight transducers, allowing transmission and reception from any one of them as well as synchronizing themselves, by hardware, with other stages. Furthermore, each stage is connected via a LonWorks bus [17] to a high-level stage that will carry out all the management tasks for the whole sonar module. In this development, traditional electrostatic *Polaroid* transducers [18] have been replaced with *Murata* piezo-electric ones [19], which have the advantage of being smaller and easier to excite. Figure 5 also shows an overview of the final design. Thirty-two transducers are used (in groups of eight placed in each corner of the wheelchair).

The ultrasonic system, when compared to classic ones [20], introduces the following new features:

- A modular design based on a LonWorks fieldbus, which allows easy reconfiguration and adaptation to any mobile unit.
- Total configurability: at any moment it is possible to indicate which transducers have to emit and which will receive the echoes, with no limitations. Reception timing is synchronized by hardware.
- Use of piezo-electric transducers of small diameter, which makes the installation in systems such as wheelchairs easier, where ring-shaped distribution is hampered in the forward area.
- A specific processing system based on a DSP, which permits computing tasks to be carried out inside the ultrasonic module itself, delivering only high-level information instead of raw data over the local network.
- Data processing is carried out by the dedicated DSP with two aims: to quickly detect potential imminent collisions with obstacles and, in the long term, to build a map of the reflected targets using true values superimposed on a grid of the environment [21].

Infrared Modules

The role of the infrared sensors is to detect floor unevenness or to obtain definite profiles of certain objects (for example, edges of doors); these tasks cannot be done by any ultrasonic system because of reflection problems or low precision. Two different systems have been developed as follows:

IRED EMITTER AND PSD AS HOLES DETECTORS

This sensor, the configuration of which is shown in Fig. 6, makes distance readings up to a point marked on the floor about 2 m in front of the wheelchair. This method can detect unevenness in the path ahead of the wheelchair (e.g., steps going up or down). Geometric constraints [2] applied to the signal captured by the PSD allow the calculation of the distance to the impact point of the infrared beam, by triangulation.

One of the advantages of this sensor is its reduced cost, although it operates safely only in indoor environments.

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LASER EMITTER AND CCD CAMERA DETECTOR (ACTIVE VISION)

This sensor module obtains 3-D position of multiple points from obstacles and the physical limits of the environment around the movement field. A laser emitter projects a plane-form beam over the scene. From the image captured by the CCD camera, the points belonging to that beam are segmented and triangulation is applied.

To obtain a wide field of vision, a wide-angle optics is necessary, but it has to be modeled to correct its nonlinear behavior and in order to calibrate the system. Field of view exceeds 100º with optics that have a focal distance of 3.5 mm. Measures taken from different points of the scene in front of the sensor can then be used to build up a rather accurate occupation map of the environment.

Figure 7 shows an image (captured through an IR filter) of a scene and the beam points obtained therefrom. Note the effective elimination of noise sources such as fluorescent lamps, windows, etc.

Using Artificial Landmarks

In the mobile robotics field, there are many solutions that use computer vision to detect the environment and to help navigation modules in their task, but some application-conditioned constraints apply in assisted mobility: on-board computer power needs to be balanced between cost and real-time performance.

Some solutions that are very effective in other applications cannot be applied to an autonomous wheelchair because of both cost and processing time. For example, let's think that a typical user would like to drive the chair at speeds up to 5 m/s.

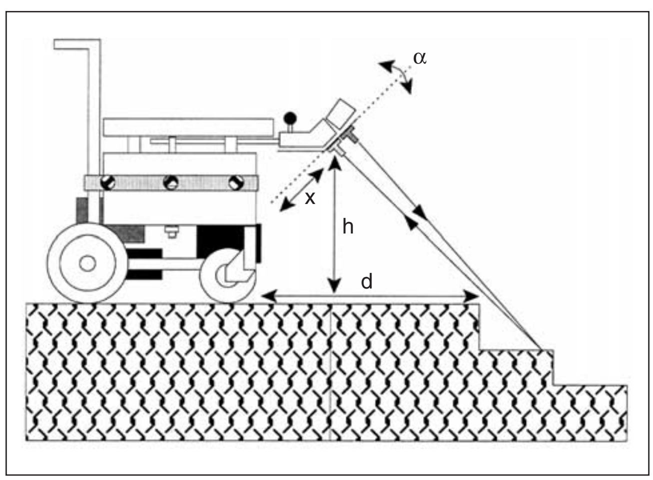

Fig. 6. *IRED and PSD configuration on the wheelchair.*

Even by reducing that maximum speed, the processing time has to be very short for comfortable driving. Other questions to keep in mind are related to battery life and the power drain of the electronic system.

To keep computing needs inside the limits of low-power and low-cost processors, an absolute positioning system based on artificial landmarks has been developed. The landmarks are simple A4 paper sheets (21×30 cm) with a black-and-white pattern printed on them. Positioning is performed by measuring the landmark distortion in the captured image (Fig. 8), which gives both relative position and orientation of the wheelchair.

Landmarks must be placed taking in consideration two constraints: all of them must be located at heights over 1.5 m (height of the camera), and each entrance door must be signaled with one landmark right above it. Those constraints simplify navigation and vision system requirements.

The basic landmark consists of a centering pattern and two groups of black-and-white bars located on both sides of the mentioned pattern. The two groups of bars meet the decimal digits codification standard covered by the UPC/EAN standards for commercial barcodes, which represents a useful way of codifying the landmark for its later recognition and the consequent localization of the mobile unit. In short, the codification allows up to 200 different codes to be assigned, including a simple error control (parity).

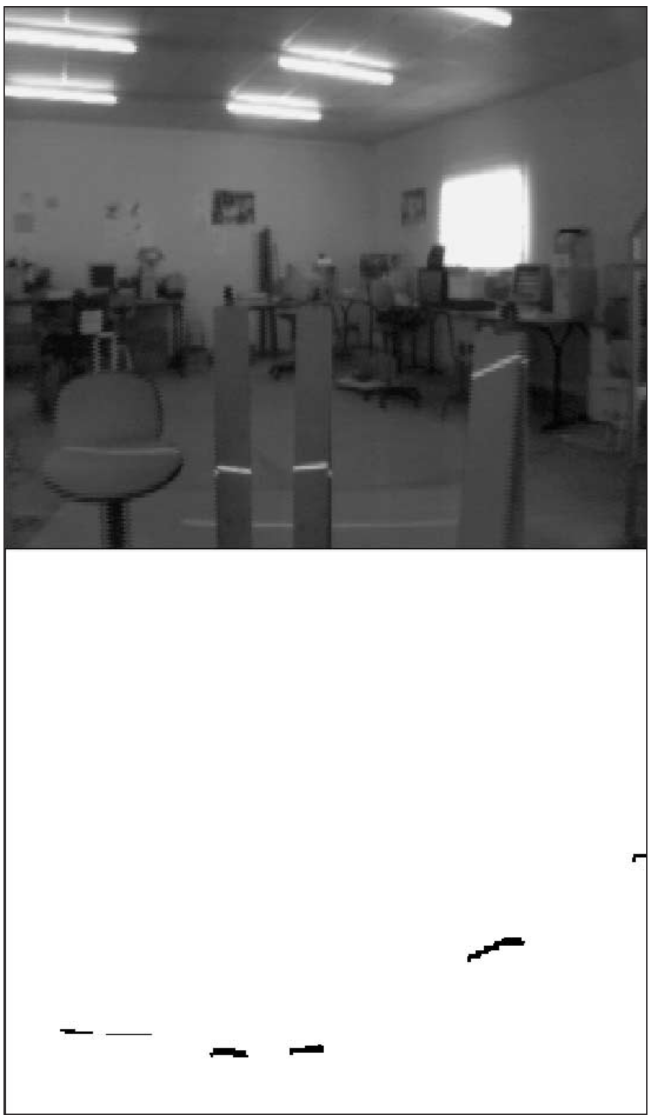

Fig. 7. *Object location: lightened scene (top) and segmentation (bottom) with noise elimination.*

Control and Navigation

In order to make the movement task easier for the user, with different sorts of disabilities, a navigation strategy has been suggested in which the user only has to communicate his motion desires to the chair at a level higher than that of the definition of the trajectory to be followed, even inside a complex location space such as a building. Once the trajectory is defined, the control system has to guarantee a comfortable path tracking (high-level control) from the user's point of view and under changing conditions of excitation of the motion actuators linked to the active wheels (low-level control). Figure 9 shows this double level of control.

Control Solution

Bearing in mind that user's comfort will depend on, among other things, the degree of control of the wheelchair's motion actuators, the adopted solution is based on the optimization of their response, taking into account both mechanical and electronic limitations. In addition, the control algorithm adapts itself to possible changes of inertia, variations of internal parameters, and working conditions of the motors.

Usually, powered wheelchairs present a differential traction structure with two driving rear wheels and two free front wheels (castor). The drive system behavior is fairly linear, except for the dead zones and those where there is response saturation. In order to compensate for the action of external disturbance torques, (surface roughness, friction, etc.), and unwanted effects such as the variation of internal parameters and operation conditions with time, an adaptive control strategy has been carried out for motion actuators. Furthermore, the control law minimizes a behavior index regarding physical limitations of the plant, mainly those related with power consumption and velocity of actuators, so the solution lies in an optimal adaptive control [22].

Related to path tracking, a mixed optimal-fuzzy control strategy has been designed and tested. Controlled variables are the traction velocities of motion actuators (right and left wheel speeds: ω_r and ω_l), used as a reference for the low-level control. In accordance with the diagram shown in Fig. 9, the path control loop has to generate linear velocity V and angular velocity Ω set points. The control solution outlined for the external loop includes two control subsystems with independent parameter adjustment: a) optimal control of the angular velocity Ω, to cancel out the wheelchair location and orientation errors, and b) fuzzy control of the linear velocity V.

Decision factors or inputs to the fuzzy controller are the trajectory curvature at the point where the chair is located and its distance to the destination. This allows high velocities to be avoided in tight curves, which could generate skids that unqualify the encoder information, and also to avoid abrupt braking when arriving at the destination point.

Navigation Skills

The automatic navigation strategy incorporated in the wheelchair is based on the reactive generation of trajectories and their tracking in a closed loop using the previously described control systems. The necessary information for this comes, on one hand, from encoders associated with the active wheels and, on the other hand, from the rest of the sensory systems that detect and locate obstacles in order to avoid them while getting data from the environment.

Possessing a stored map of the environment results in the absolute location of the mobile unit at all times, as well as in tracing and modification of the trajectory to be followed, if necessary. Nevertheless, some parts of the navigation tasks have a strong reactive component.

Navigation tasks need a full mapping of the environment, so processors on-board need to store those maps in a full and extensive database with all the problems related to wide information processing. In SIAMO, part of the local intelligence has been translated to the building intelligence: the building's distributed electronic system updates the map that the wheelchair system uses.

This system is shown in Fig. 10. The serial bus used (the LonWorks system) has a strong application in building automation; among the communication media there are wireless drivers available as infrared or radio frequency links. One contactless node, equipped with a wireless driver, can be placed on the main doors and loaded with a full description of room identification, landmark location, and routing inside the section of building accessible to it. So, the only detailed mapping needed can be stored "on-the-fly," just while entering a new building section.

This integration between wheelchair and environment [23] has many advantages: computing-power needs decrease strongly, and navigation capabilities can grow and cover even places never visited before, such as public buildings (hospitals and business or government offices). Some other advantages of the building integration nodes are the access from wheelchair electronics to any electronic device connected to the building local net; this is not related to navigation, but it is really useful because it opens a full range of actions that can be made on-board the wheelchair, such as to give (or even receive) commands to lifts, lights, or other home devices.

Hardware architecture for the execution of control tasks of motion actuators and for path generation and tracking, together with other functions related to the chair's navigation (representation of the environment, man-machine dialogue functions, etc.), is based on custom electronic cards that use three key devices: a DSP, an FPGA, and a NeuronChip [17]. As an example, we will describe two of these cards in the following paragraphs.

On the navigation control card, the DSP, using the information received from the group of sensory systems and the man-machine interfaces, establishes the trajectory to be followed and is also responsible for their reactive tracking, computing the corresponding actuations. The FPGA is responsible for decoding signals from the encoders and for calculating the relative location of the mobile unit. The NeuronChip is the device that acts as an interface between this card and the rest of the architecture connected to the LonWorks serial bus.

On the motion actuator control card, the DSP translates the global variables (V, Ω) to local ones (ω_r, ω_l) and executes the optimal-adaptive control algorithm. The FPGA helps to

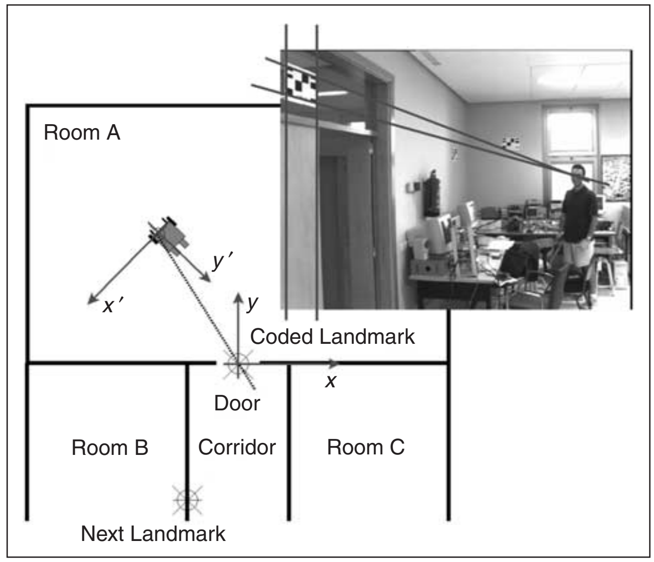

Fig. 8. Landmark-based absolute positioning.

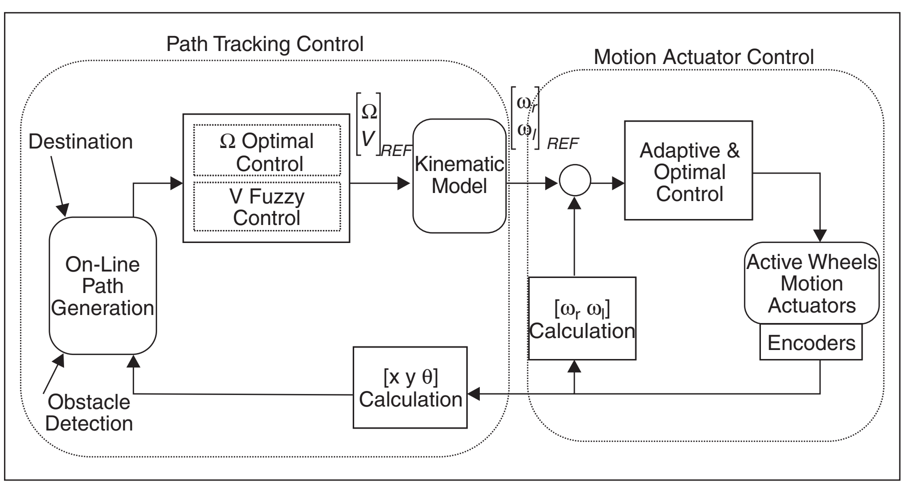

Fig. 9. Double control loop: motion actuators and path tracking, used in the guidance of the wheelchair.

generate the PWM actuation according to set points and the speed information coming from the encoders. The function of the NeuronChip, once again, is the interface between this card and the local network.

Summary

The Integral System for Assisted Mobility (SIAMO) has been developed to give improved mobility assistance to wheelchair users who cannot easily operate conventional-powered units. Furthermore, the system has the characteristic of being modular, which allows it to be easily adapted to each user's specific requirements, depending on the type and degree of disability.

To keep computing needs inside the limits of low-power and low-cost processors, an absolute positioning system based on artificial landmarks has been developed.

Sensory system and alternative guidance devices allow different operation modes to be configured, always guaranteeing user safety, and taking into account that the greater the user's capacity, the lesser the functionality demands made on the chair and vice versa. Among the guidance alternatives, up to five possibilities have been studied and developed, three of which have been optimized for severely handicapped people: breath-expulsion driving, head movements, and EOG commanding, in addition to digital joystick and guidance by voice.

Driving by breath-expulsion and voice-command guidance have been thoroughly tested on different prototypes and by different users, with highly satisfactory results and with only a short period of training required. The alternatives of guidance by head movements and EOG have also 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 both the commanding and training simpler. Of these two systems, the most interesting is the first one, since it is a nonintrusive alternative (the user doesn't need to place any device on his body); however, it has the drawback of presenting functional difficulties in environments where light conditions are not homogeneous.

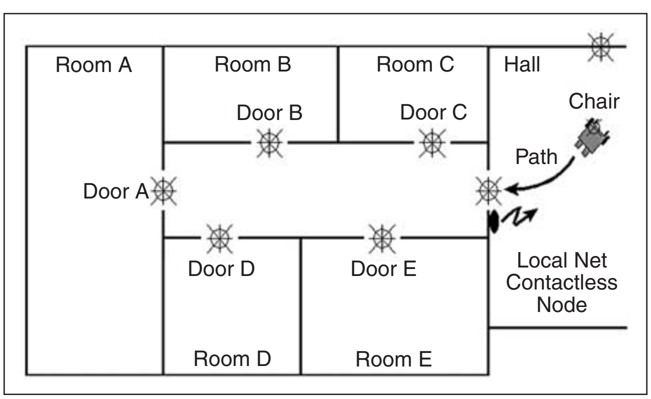

Fig. 10. *Local mapping-based navigation: self-identifying environment.*

The sensory system has been designed so that it meets safety objectives at very low levels and allows autonomous guidance in structured environments. Thus, the ultrasonic system made up of a total of 32 transducers (covering a sector of 240º around each corner of the chair) allows for quick and easy detection of obstacles, avoiding potential collisions, and also the construction of environment maps in greater detail.

Possible floor discontinuities (for example, steps or holes) can be detected by the IRED-PSD detector at distances within the range of 2 m in front of the chair. A laser emitter and CCD detector camera (active vision) can be used to obtain 3-D information of multiple points of the environment, facilitating the detection of obstacles and open doors. However, infrared systems have some drawbacks in those environments where strong radiation sources exist over the same wavelength of the laser; for example, in outdoor spaces with strong solar radiation or windowed corridors with direct sunlight. For safety reasons, this kind of sensor must be fitted only to indoor wheelchairs until further research obtains good results outdoors.

A navigation strategy has been designed, using the sensory information, that makes driving the chair easier. Depending on the type and number of modules fitted, and if the degree of the user's disability is high, it is only necessary to indicate the destination point. The navigation system incorporates the capacity of modifying the trajectory depending on the obstacles detected. The solution adopted is based on the storage of maps complemented with two subsystems of autonomous navigation: one of them using the potential field paradigm and the other applying the reactive approach. Furthermore, the possibility of having totally autonomous guidance using artificial landmarks is included. These landmarks are detected by an on-board CCD camera that allows the absolute coordinates of the chair in a certain environment (hospitals, nursing homes, etc.) to be known. The optimal-adaptive control of the motion actuators along with the optimal-fuzzy trajectory tracking solution contribute to a comfortable use of the wheelchair despite temporary variations of factors such as friction of the movement surface, inertia associated with the chair, drifts due to the performance of motors and associated electronics, etc.

In summary, the SIAMO project allows wheelchairs to be configured with different features, both at the level of guidance strategies and that of environment capture; its modularity makes the system well suited to be easily adapted to specific users' needs. It also has an appropriate set of different driving modes according to the user's capacities and the structure of the environment.

Acknowledgments

This work has been carried out thanks to grants received from CICYT (Interdepartmental Science and Technology Committee, Spain) project TER96-1957-C03-01.

Keywords

Autonomous wheelchair, modular system, human-machine interface, guidance by breath expulsion, guidance by head movements, guidance by electro-oculography, guidance by voice recognition, ultrasonic sensors, infrared sensors, artificial landmarks, optimal control, autonomous navigation.

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