Human-Machine Interfaces and Sensory Systems for an Autonomous Wheelchair

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Abstract. *This paper presents some results of the project called: "Sistema Integral de Ayuda a la Movilidad -SIAMO-" (Integral System for Assisted Mobility). The SIAMO can be installed over any standard powered wheelchair and includes a complete user-machine interface, motor control modules and safety and autonomous guidance systems. Special care has been taken in designing and testing the Human Machine Interface (HMI) and Sensory System on-board, to build a wheelchair with a convenient performance/cost ratio. HMI includes a full set of linear and state-based input devices, each of them able to drive the chair using any of the capabilities of the user; output devices feedback the state of the chair to user. The sensory system includes contact and contactless devices, as ultrasonic and infrared range finders, and a vision-based self-localization system for safety and navigation task. Integration with the Building capabilities are also possible thanks to the flexibility of the Serial Bus used.*

1. Introduction

It is known that the application of mobile robotics techniques on the mobility assistance field provides a better quality of life to those people with strong motion and sensorial restrictions [1]. Therefore, many research groups have addressed the question of adding more or less intelligence to the machine (a standard powered wheelchair in most cases) but always under user control or commanding despite his disabilities. So, the study of an appropriate Human Machine Interface (HMI) between user and the electronic chair is an important field in assistance robotics [1, 2, 3].

Other questions as safety, navigation and driving comfort, must be solved as well. The wheelchair must be equiped then with a full sensory system, able to detect obstacles, holes and other dangerous situations. Nevertheless, the performance/cost ratio must be kept in a reasonable quantity using just the right number and type of sensors.

The research group on assisted mobility of the Electronics Department of the University of Alcalá has been working in this field for more than six years. As a result of this work several wheelchair prototypes have been developed including various guidance alternatives and different types of safety sensors and tracking aids [4] [5].

Current efforts are focussing on the design of modular systems (that could be able to adapt themselves quickly to user demands), and in the incorporation of guidance alternatives for cases of severe disability. Other main guidelines that complements the overall system are the optimization of the autonomous guidance behaviour with the design of navigation aids with a better performance/cost ratio and the study of other options of interface systems that could improve human-machine communication even in cases of very severe physical limitations of the user.

2. Human-Machine Interface on-board of SIAMO: guidance alternatives

The exchange of commands (HMI inputs) and state information (HMI outputs) between wheelchair and user is customized in accordance with the particular needs of the user, i.e., degree and type of disability, facilities of the system fitted, etc.

State of the wheelchair state and feedback of orders reach the user by different means. This information can be relayed visually or acoustically. Some of the *output modules* designed are: LED indicators for scanners, a low-cost low-resolution LCD display of 2x16 characters, a graphic high resolution display and a voice synthesiser.

Standard *input devices*, as joystick or scanners, have been tried and can be easily added or removed thanks to the open architecture of SIAMO system. For inputting orders, the user of SIAMO has many alternatives. As a primary option, for those who can use them, input to system could come from a linear -conventional- joystick, a discrete -programable- joystick and several kinds of buttons or switches; more complex input devices, as a graphical touch screen and a vocal command processor with a voice recognition unit may be used as high-level or low speed inputs in semi-autonmous modes.

Nevertheless the more interesting features of the Human-Machine Interface designed in SIAMO system are those aimed to give real driving capabilities to severe handicapped people who cannot drive easily other conventional devices. For those with deep disabilities, two driving alternatives have been designed and tested: guidance by breath-expulsion and guidance by head movement. It should also be stressed that all the input methods, including the linear joystick, have got a programmable controller so it is possible to have both semi-automatic and automatic command modes. In next paragraphs a short description of two of the most interesting input devices will be done.

2.1. Breath-expulsion guidance.

Breath units can be found as interfaces for tetraplegics, but usualy as another way to activate a switch in ‘scanners’ that work as follows: an output device (as an array of LED’s) change a pattern in a cyclic way and user activates the one desired by means of a simple action, as blowing over a preasure switch.

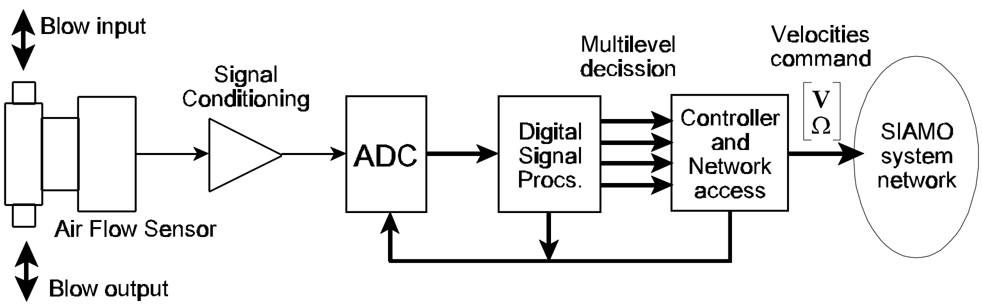


Figure 1.- Blocks diagram of the ‘Blow-driving’ unit.

The one designed in SIAMO works in a very different way: it is an almost real time driving unit. A differential air flow sensor with a linear output is used (figure 1), so it is possible to detect both strength and direction of breathing. The output of such sensor is processed and as a result codified commands are sent to the navigation modules of the wheelchair through a LonWorks data network on board [6]: SIAMO has got such a Serial Bus in order to provide to the system a high flexibility, modularity and environment integration performances.

Signal coming from the air flow sensor is clustered into five levels, according to the following labels: 'Strongly out', 'softly out', 'nothing', 'softly in' and 'strongly in'. Activation thresholds are asigned dinamically because some shifts in sensor readings can be found depending on variations in air temperature and humidity. Each output cluster is processed then as an input to different state machines, each of them related with a specific behaviour.

Taking into account time and cluster, a velocity vector command can be sent to SIAMO network at a minimum rate of 120ms. The velocity vector includes a proposal to linear and angular speeds (V and Ω) that need to be integrated by a controller node with the information coming from the environment [7] if such a performance has been included; if it is not included that velocity vector goes directly to the motion processors.

With an *easy-to-use* breath code it is possible to control both linear and angular velocities and to stop the chair in case of troubles. This system is fast enough to allow driving in narrow places, public spaces, corridors and even through broad doors.

2.2. Guidance by head movement.

Another way of human-machine interaction which is very interesting in the assistance to the mobility of disabled people [8] is the tracking of the direction where a person is looking at. In doing this (see figure 2) a color micro-camera have been placed in front of the user, in order to get face images. These images are digitized by a frame grabber and loaded into the memory of a PC Pentium based industrial mini-board. The system is non-intrusive and it allows users full visibility and freedom of head movements, all that with a random background.

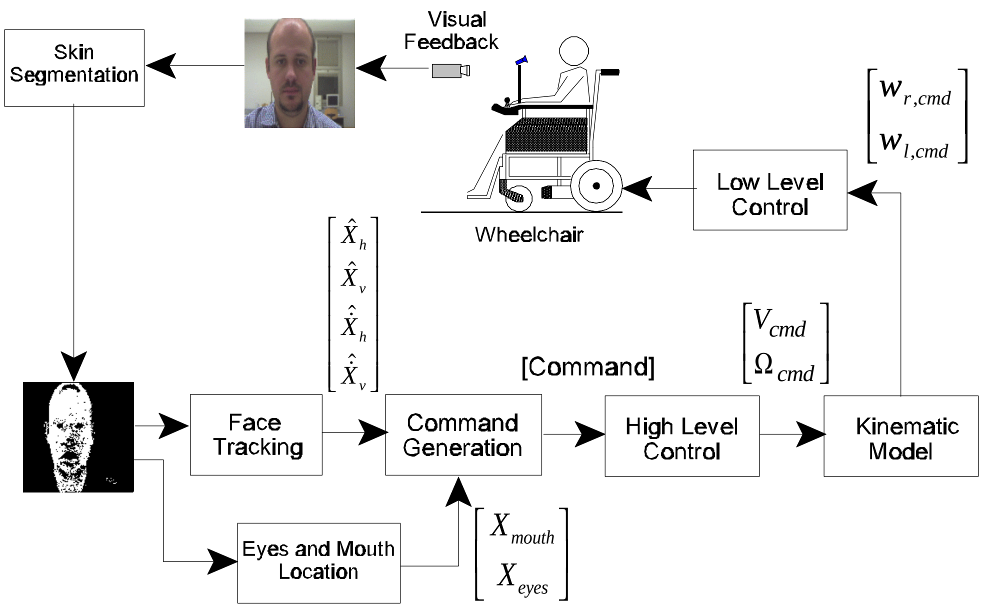
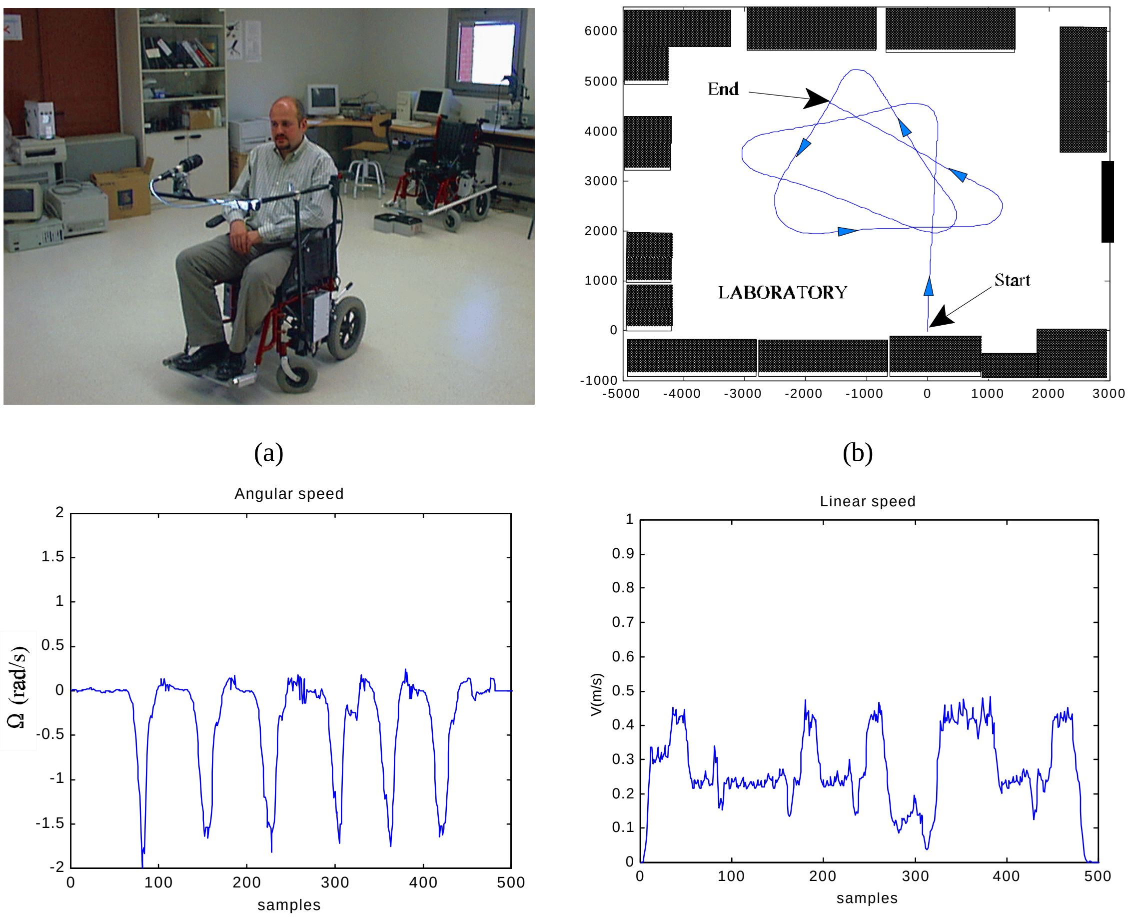


Figure 2. Architecture of the guidance by head movements

The head tracking system is based on skin segmentation by an adaptive skin color model, this one is initialized by a clustering process using unsupervised competitive learning. On the skin blob some parameters are calculated to track the face: center of gravity (x,y), horizontal (h) and vertical (v) size of the face, in order to be able to get face position and orientation. A zero-th order recursive estimator is used to recover and track two independent state vectors: one to the horizontal variation, X_h =[x,h], and the other to the vertical variation, X_v =[y,v].

Analizing the vector states and their derivatives a fuzzy control has been performed in order to codify commands depending on the head orientation; input clusters and their labels are the following: ‘Right’, ‘Left’, ‘Forward’, ‘Backward’, ‘Up’, ‘Down’ and ‘Fixed’ (reset position). After clustering, different commands are generated and sent to motion controllers through SIAMO serial Bus [6][7]. Figure 3 shows the results of a test run: in (a) a picture of the wheelchair shows the camera arrangement, while in (b) the path followed inside a room of 8x7m is drawn, only left turns were made. Evolution of both, angular and linear wheelchair's velocities, is presented in (c) and (d). This test lasted 100 seconds, taking 5 samples per second. Accelerations of the wheelchair during straight sections can be clearly apreciated. Also, the wheelchair decreases its speed before performing a curve.



(a) (b)

(c) (d)

Figure 3.- Test run: (a) User and chair; (b) path registered; (c) angular speed plot; (d) linear speed plot.

3. Detection of environment and navigation

Detection of the environment is essential, both from the point of view of safety -in order to avoid collisions and falls- and tracking. In the latter case sensory requirements of the system will also bear a close relationship with user needs which will depend also on user’s own degree of autonomy. The on-board sensory structure of the SIAMO system, therefore, includes different modules to be fitted or not depending on the final configuration required.

At the lowest level bumpers and contact detectors can be found to detect collision situations. As higher level modules, ultrasonic, infrared and vision sensors have been used.

3.1. Ultrasonic Sensors

The role of the ultrasonic sensors is to detect the presence of obstacles in the environment through which the wheelchair is moving. Some different configurations have been studied, but taking into account some questions as user comfort, modularity, low cost, minimum size, hardware optimizacion and good performance, a new system based on an array of four modules have been developed. Figure 4 shows their arrangement (S1 to S4) on wheelchair's corners.

One ultrasonic module controls up to eight transducers, allowing emission and reception from any transducer, as well as a synchronised reception. Each module is connected via a *LonWorks* bus to a higher level system which will carry out all the management tasks for the sonar subsystem. In this development, traditional electrostatic *Polaroid* transducers have been replaced with *Murata* piezo-electric ones, which have the advantage of being smaller and easier to excite.

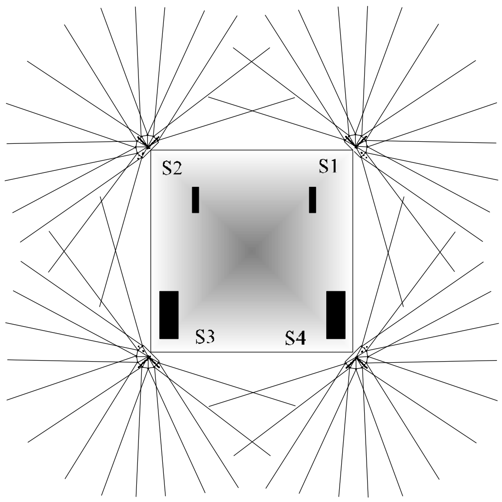


Figure 4.- Distribution of modules around the chair.

The ultrasonic system introduces, when compared to classic systems, new and interesting features: *full flexibility*, because at any moment it is possible to select which transducers have to emit and which ones will receive the echoes, with no limitations; the use of small size *piezoelectric transducers* makes easier their installation in systems such as wheelchairs, where ring-shaped distribution is hampered in the forward area; also a *specific processing system* have been designed based on a DSP, which allows mapping task to be carried out in the sonar module itself, avoiding high volume data transfer over the local bus.

3.2. Vision sensors

Although a camera is used in the head movement subsystem, this can not be thought as a Vision Sensor because its function is to detect User commands instead of environment data. SIAMO uses vision sensors to detect the environment and to help navigation modules in their task but some constrains applies: to balance computer power, cost and real time performance.

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. Landmarks are simple A4 sized paper sheets (about 21x30cm.) with a black and white pattern printed on them. Positioning is performed by triangulation after identification of three or more landmarks.

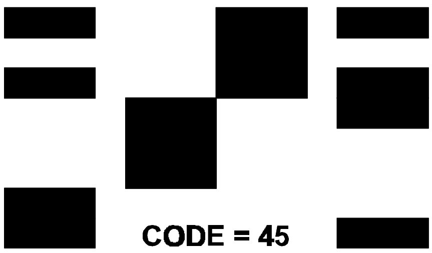


Figure 5.- Original landmark

Figure 5 shows the basic design of the artificial landmark used. It has got a centering checkered pattern, used in long-range detections, and two more patterns both sides of it. Side patterns are standar UPC/EAN barcodes, that allow landmark codification and recognition. The number of different codes is 400 but it has been reduced to 200 in order to get some kind of error detection.

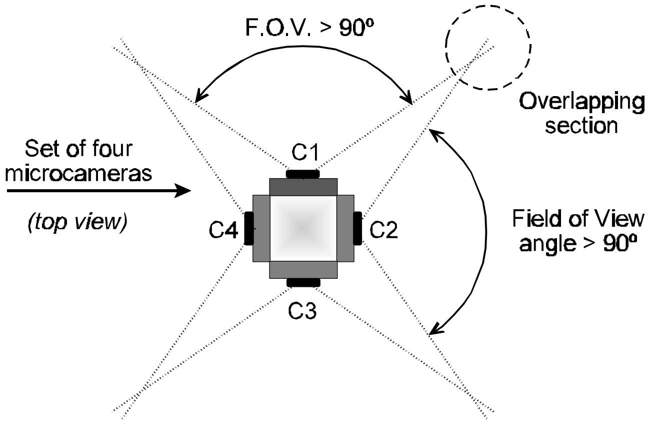


Figure 6.- Omni-directional camera.

Instead of an active vision system, landmark seeking and tracking is performed using a pasive omni-vision system, that is based on the image taken through a set of four micro cameras mounting wide angle lenses with a field of view (FOV) higher than 90 degrees, as shown in figure 6. Some overlapping of the cameras FOV is needed to recover a full 360 degrees image.

The size of barcode symbols, 2cm wide, allows appropriate readings in distances up to 5m, using SVGA cameras with a FOV of 90 degrees. Nevertheless, centering pattern (6cm wide) can be detected at three times that distance (up to 15m). So, if a detailed mapping of the environment is known and nearer landmarks have been identified, it is possible to do path tracking and navigation tasks in relatively large environments.

4. Conclusions

The most important objective of the SIAMO system was to provide an easy driving of the wheelchair; so, a full set of guidance alternatives can be selected improving Human-Machine Interface to severely handicapped people. Also big efforts have been done in designing sensory systems for safer driving while avoiding collisions and in giving useful tools -based on artificial landmarks- to on-board navigation processors.

5. Acknowledgements

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