Multimodal Laser-Vision Approach for the Deictic Control of a Smart Wheelchair

Frédéric Leishman, Odile Horn, and Guy Bourhis,

LASC, Université Paul Verlaine de Metz, France, 2008
{bourhis, horn}@univ-metz.fr, leishman.fred@orange.fr

Abstract. This paper presents the design of the deictic functionalities for the navigation of a semi-autonomous powered wheelchair driven by a person with disability. Such functionalities, primarily based on a command by vision and a control by laser, offer an ergonomic mode of control to the user. The first functionality implemented is an automatic passing through narrow passages. The user must point the objective to be passed through, on an interface presenting an image of the environment. Then, the wheelchair moves in autonomous mode. Firstly, we describe the controlling mode for the wheelchair, the perception of the environment, the user interface and the means of path following. Then, we present and comment the results obtained during the experimental tests.

Keywords: Smart Wheelchair, Vision, Deictic Control, Laser Range Finder.

1 Introduction

At present, wheelchairs with manual or powered propulsion provide mobility to a great number of people with disability. However, much force is required to drive a traditional wheelchair, and a certain level of dexterity to drive a powered wheelchair, leaving the use of wheelchairs still difficult for a significant population of disabled people. An in-depth study clinicians and doctors [1], estimate them from 1.4 to 2.1 million people lying under this case in the United States. This highlights the utility of the studies undertaken since the mid-eighties on the development of smart wheelchairs. Their aim was to facilitate the control of a wheelchair. A state of the art was carried out in [2] presenting the various types of technologies, methods of instrumentation and control used, as well as the list of research projects carried out. The first systems consisted of a mobile platform equipped with a seat and sensors. They used technologies of autonomous mobile robotics for the types of sensors used (Ultrasounds, Infrareds or Vision) as well as for the movement algorithms (obstacle avoidance, wall following, etc). For example, Mister ED [3] and Vahm-1 [4] was composed of a robotic platform base equipped with ultrasound sensors. Many projects were developed thereafter, around commercial powered wheelchairs undergone through heavy instrumentation, and integrating a computer and a set of sensors. The advantage was having a system focusing basically on human and thus more adapted to him. For example, Navchair [5] is a prototype design originating from the Lancer™

model, equipped with an array of ultrasound sensors and a computer. Its movement algorithms are reactive, based on the histogram of obstacle densities.

We have developed a prototype, the Vahm-2, at our laboratory based on the PowerPush™ wheelchair equipped with autonomous and semi autonomous functionalities [6]. Many other prototypes were developed, which differ in the possibilities in control methods, the modes of navigation, the nature of environments considered and the data processing methods [7].

Some recent works aim at designing lighter structures providing specified smart functionalities and which are likely to adapt to all types of electric wheelchair. Thus the SWCS [8] proposes assistance in navigation through a system comprising of US, IR sensors and Bumper. Moreover, recent progress in terms of miniaturization and cost suggests certain types of sensors, such as laser range finder sensors or cameras, to be more adapted to these problems.

The objective of these wheelchairs is to allow autonomous movements to the user without depriving him of the possibility to intervene. To find a level of comfort between the wheelchair's autonomous control and the control of the user over the actions carried out by the wheelchair, one can ask: how as well as possible to employ human intelligence in this human - smart wheelchair association? [9] and [10].

The best way of letting the user command over the process is to consider his cognition during movements. More precisely, the actions should be oriented towards complementary control between the wheelchair and the user. That's why the choice, concerning the user interface and the user input mode on the wheelchair, are very important. The current input control mechanisms range from the standard joystick based control or switching sensors (pneumatic switch, pushbutton, etc), to more sophisticated input mechanisms such as treatment of the physiological signals (EOG), video analysis of the user (position of the face, eyes), or more recently, rests on the interfaces projected by video projectors and analyzed by camera [11]. On the matter, a promising approach is "the deictic" [12]. The concept of a deictic interface lies in proposing an outline of the environment to the user on which he points the localization that he wishes to reach. It has the advantage of being very intuitive and has already been considered in two projects, [13] on a mobile robot and [14] on a mobile platform.

We have developed our own deictic control for a powered wheelchair. In the following, the methodology adopted for a particular functionality, the passing through of narrow passage, is presented. Firstly, the means implemented to be able to control the wheelchair, the mode of perception of the environment and the deictic approach applied to our interface with the user are exposed. Next, we discuss the method of detection of the narrow passages in the environment, the generation of the trajectories and the mode of control of the wheelchair. Lastly, the experimental tests carried out, starting from this functionality, are described, three characteristic examples are detailed and the set of tests achieved are analysed. Thus the potentialities of this approach are emerged.

2 Methodology

Our problematical is to define a set of behaviours of the wheelchair, making it possible to drive it by means of a deictic command. Using a light structure made up of a computer, a laser range finder sensor and a camera, the idea is that the user should be able to control the wheelchair by simple and intuitive instructions such as: "I want to pass this door ", "I want to reach this point " or "I want to follow this wall". Thus, the user will have to provide (through an interface) two types of information to the system: the type of action to be carried out and the localization of the target in the environment. In this regard, our first conception is the functionality of automatic passing through a narrow passage. The image from the camera, fixed on the screen, is used as an input interface with the user where he indicates the passage to be reached. Measurements from the laser sensor are then used to determine the trajectory to follow. This first application enables to outline various possibilities of this “vision-laser” association.

2.1 Control method of the prototype

The Vahm-3 prototype developed at the laboratory is in fact, the instrumentation of the model of wheelchair Storm™ manufactured by Invacare. It is equipped with a computer, a laser range finder and a camera, (Fig. 1). This wheelchair is usually controlled by a joystick, while our objective is to control it through instructions sent by program.

One of the problems encountered in our approach is the impenetrability of existing technology which, moreover, varies according to wheelchair. Indeed, we have no knowledge of the way of generating the voltages from the joystick, of the communications protocol between the different elements of the wheelchair (for example the DX bus) and of the internal regulation of the vehicle. In order to bypass this problem and to return our developments adapted to all wheelchairs, we design our system by "simulation of the joystick", i.e. the trajectories will be expressed in a succession of joystick positions (defined by the angle and the amplitude) which will be converted into voltages sent to the motors. In this aim, we established a fuzzy logic module, which determines the voltages sent to the motor control according to the position of the joystick. It is based on qualitative considerations which reproduce the movements as close as possible to actual joystick control. The design of this module [15] can make our system easily adaptable to any commercial model of powered wheelchair.

Two types of control are thus possible: the usual manual mode by the joystick and the programmed mode which - from the simulated position of a joystick - will send the signals to the motor control systems. The achievement of automatic movements will thus require the calculation of a succession of virtual positions of the joystick.

2.2 Perception of the environment

We have used two external sensors in our design. The first sensor is a camera, giving an outline of the environment which is understandable by the user. Currently, the use of video is dedicated for the user interface that we will detail below. The other sensor is a laser range finder sensor that enables us to measure a range of distances of 0 to 4 meters to the obstacles around the wheelchair on a circular plane of 0° to 240° with a resolution of 0.36°. These measurements are conditioned into a set of points characterized by their Cartesian co-ordinates in the frame of reference of laser sensor. Laser measurements are used to perceive the environment, and thus to program its movement.

Fig. 1. Vahm-3 wheelchair.

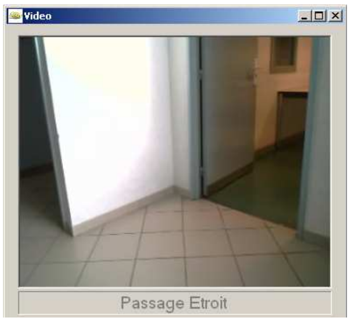

Fig. 2. Interface with the user.

2.3 Deictic interface

The Human Machine Interface between the user and the wheelchair is designed to minimize the user workload, enabling him to control the wheelchair as simply as possible. As discussed earlier, the user has to provide two pieces of information to the system, the type of action to be carried out and the topographic localization of the target in the environment.

Concerning the first part, we currently confined ourselves to the behaviour "passing through a narrow passage". Thereafter a possible choice of behaviours will be introduced, proposing a selection of activation buttons presented to the user on the screen. For the second part, the user should indicate on the interface, the target localization in the environment. Thus the interface must present the most comprehensible vision of the environment to him. We have chosen to display the video image directly from the camera as a reflection of the environment (Fig. 2). On this interface, the coordinates of the target are determined with a click on the screen in the target area (currently this click is made via a mouse but we are considering other methods more adapted to users). This "click" has to be translated into topographic target point usable by the different elements of the system. This is a question of converting the point clicked on the screen, characterized by the coordinates (i, j) in the image, into the coordinates (x, y) of the corresponding topographic position in the plane of measurement of the laser sensor. This translation would be approximate, requiring simplifying assumptions. The first being the assumption that there are no obstacles between the camera and the point projected in the environment on the level of the laser sensor. In order to define a mode of conversion, the correspondence between certain particular points in the image and the environment is established as following.

Experimentally, we determine, in the environment, the positions of the points P2, P5 and P8, which are located in the image, in the centre of the lower edge, the centre of the image and the centre of the upper edge respectively. To do so, "landmarks" are placed in the environment so that they correspond to the points wanted on the screen and the distances ||OP5|| and ||P2P8|| are then measured in the environment. The Fig. 3 represents the correspondence between topographic localization and points of the image. The point (i, j) of the image is represented by its polar coordinates (ρ, θ) in the frame of reference of the laser. Knowing that the horizontal focus angle of the camera is 70° and that the dimension of the image is of 352*288 pixels we can calculate:

$$\theta = \frac{i \times 70}{352} \qquad \text{and} \qquad \rho \cong \frac{j \times \|P2P8\|}{288} + \|OP5\| \tag{1}$$

Then, starting from ρ and θ, one finds the Cartesian coordinates (x, y). This estimate supposes linear the relationship between the distances perceived in the image and those corresponding in the environment. It is acceptable for our application since on the one hand the passage is generally indicated to be in the vicinity of the middle of the image, and on the other hand the real localization of the narrow passage is determined with measurements of laser. Indeed, we use this conversion to obtain a first indication of localization of the passage, which allows thereafter, regain this position with exactitude thanks the laser sensor as will be shown in the next section.

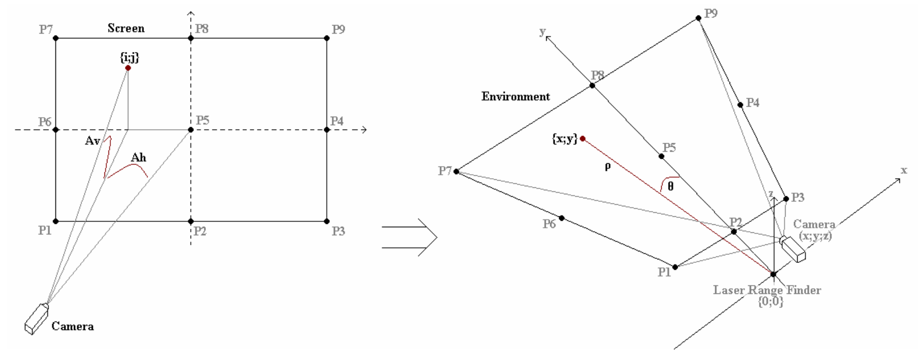

Fig. 3. Conversion of the click of the user on the video in Cartesian coordinates in the frame of reference of the laser.

2.4 Detection of the narrow passage

In order to pass through a narrow passage, it is necessary to locate it precisely in the environment, at the beginning and during the movement of the wheelchair. Using the data from the laser sensor, this is carried out in the following way.

Firstly, in the frame of reference of the laser sensor, all the possible passages in the environment are sought. A passage is defined as space between two obstacles that is large enough for that the wheelchair can pass through. It is detected in the following manner. The points resulting from laser measurement are divided into sets of obstacle. For that, a sweeping of the points is carried out. A unit is created at the first point, then, for each point, the distance from its preceding point is measured. If the distance is smaller than the width of the wheelchair, then the point is considered to belong to the unit in progress, else, a new unit is created from this point. Once sets of obstacle are defined, the minimal passages between each unit are determined which will be memorized as a possible passage of the wheelchair. We can see on Fig. 4, an overview of the narrow passages characterized by a couple (cross, round). At the beginning of the trajectory, the passage closest to the point (x, y) calculated from the user input is selected as target, while the running passage, during the movement of the wheelchair, is determined as the closest to that used in the preceding stage.

As the wheelchair moves at a slow speed, the tracking toward the same target is guaranteed. The movement stops when the laser sensor detects that the passage has been passed, or otherwise, on the user's behest, who can click on the screen at any time to do so.

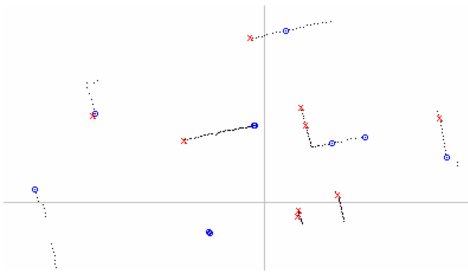

Fig. 4. Overall picture of passage in the environment on the cartography of our application.

2.5 Trajectory Generation

In order to pass through a narrow passage, the wheelchair must be positioned well in front of it before entering. This requires the definition of a trajectory which brings the wheelchair in the good orientation. In our application, the trajectory is the result of a succession of target point. By observing the trajectories adopted by a person driving a wheelchair manually and taking into account the constraints of programming, the target points are defined in the following way. Several geometrical sectors are defined relative to the limiting points of the passage and for each sector; a target point is defined towards which the wheelchair will move in order to leave the sector. We actually want to reproduce, the behaviour of a person, who drives the wheelchair in front of the narrow passage with an orientation approximated before going towards the centre of the passage while refining the orientation. We thus create three areas, each having its target point as shown in Fig. 5. In this configuration, if the wheelchair is located in area 1, it moves towards the Pc1 point and as soon as it enters in area 2, moves towards the Pc2 point, and so on. The wheelchair doesn't reach really the target point as he changes of target when he changes areas. This allows a continuous motion and transitions between the targets points remain fluid. The Fig. 6 shows these areas and points during movement.

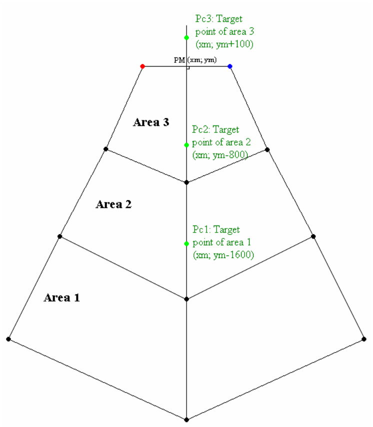

Fig. 5. Representation of the areas associated with their points target compared to the narrow

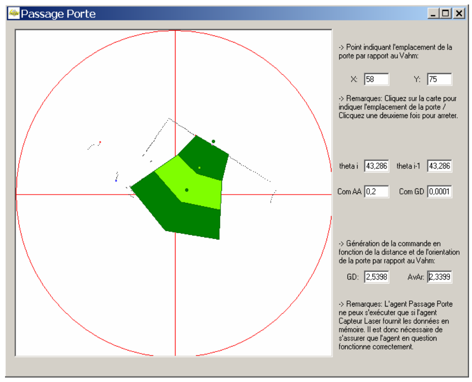

Fig. 6. Outline of the areas associated with their target points in our application

2.6 Control on a position

At every moment, the objective (input to the system) is expressed by the polar coordinates of the target point. The wheelchair must thus continuously adjust itself in relation to this one. To achieve this, a digital PID controller has been designed to generate the simulated joystick signals. In the control feedback representation, the polar coordinates of this target point characterized by a couple (angle, distance) corresponds to the error of orientation and the error of position, respectively. The role of our controller is to cancel these two errors. A diagram of the control loop is shown on Fig. 7. The PID is adjusted empirically using the Takahashi Method. This method allows adjusting the parameters of the controller in closed loop and does not require any model of the wheelchair. After refining the adjustments the following gain parameters were obtained: P = 4; I = 0.01; D = 11.

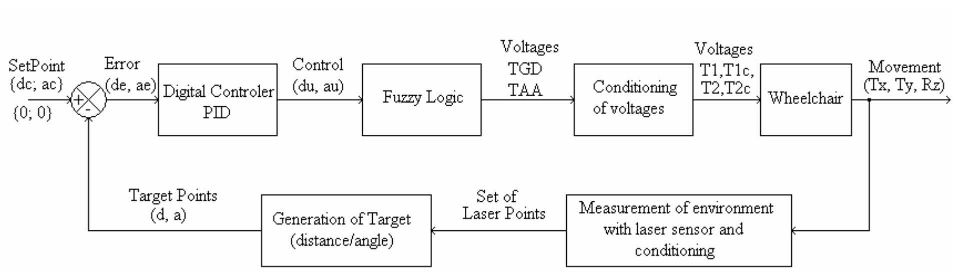

Fig. 7. Diagram of the control loop during a passing of narrow passage

3 Experimental results

For the evaluation of the methodology, a set of tests were achieved to verify its operating mode and to estimate its operational limits. A great number of courses were carried out in different places in our laboratory. Three of them are described here. For each test, an outline of the environment on the user interface is given, as well as the trajectory followed by the wheelchair. On the environment image, the arrow indicates the target pointed by the user to launch movement. The trajectory is obtained indirectly, starting from the succession of laser measures, as follows. During the execution of the procedure, the location of the narrow passage, perceived by the laser sensor, is memorized at each measurement. Thus, the movement in the narrow passage in relation to the laser reference is obtained. For more legibility, the reference frame is changed by fixing the target passage while the wheelchair is shown to move. Then, the localization of the wheelchair in this frame is recovered by projection. Thus, a trace of successive positions of the wheelchair in relation to its target is obtained. On the trajectory, the wheelchair is represented as a rectangle corresponding to its maximum expanse.

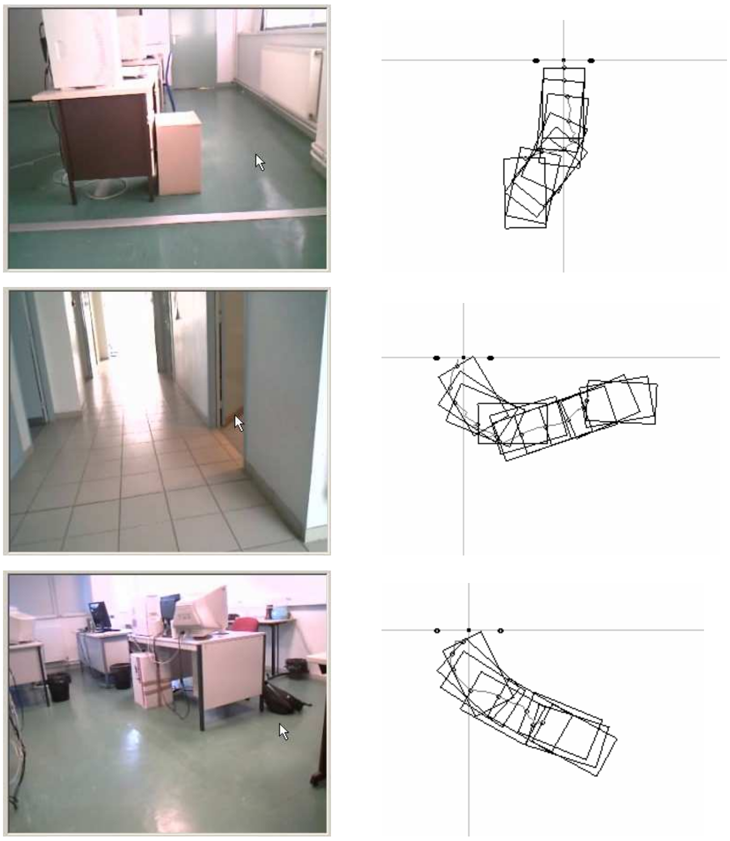

Fig. 8. Tests presenting the starting vision (on the left) associated at the trajectory of the wheelchair in this configuration (on the right).

The process of passing through the passage is considered to have been completed when the laser sensor (located in front of the wheelchair) is passed through the target. The trajectory thus stops at this stage. Then, the wheelchair must be able to pass through the narrow passage, from where the importance of a good orientation.

This functionality can be employed to pass through several types of obstacles, a door, between two tables, or two obstacles unspecified. The tests described in Fig. 8 illustrate it. It is noticeable that the trajectories obtained are close to those which a human would have followed manually. For example, one can see in the second test, that the wheelchair moves away from the door so as to approach this one in face. This is made possible by our method of trajectory generation. One can thus see the importance of the repositioning and orienting before entering. Indeed, if the wheelchair takes aim at the centre of the passage from the beginning, he could not pass this one. The fluidity of the movements can also be noticed by analyzing the variation of distance between the rectangles. The expanse of the wheelchair has been represented by a rectangle at each interval of three measurements, i.e. at regular time. The difference between the rectangles thus represents the speed of the wheelchair during movement which is almost constant (around 0.3m/s).

4 Discussion and conclusion

The implementation of this first functionality and the profitable tests carried out show that this association command by vision and control by laser is a promising design for the deictic control of smart wheelchairs. During the many tests carried out, two types of limits could be identified. First of all, the limits of the methodology itself are put in highlight as follows. So that the functionality of narrow passage is efficient, the wheelchair must start from a certain distance from the passage (at least 1m), since it must follow a succession of target to pass through the objective. If it is too close, the target point retained would actually be the centre of the passage. It would arrive in front of the narrow passage with a wrong orientation and fail. In such a configuration a human driver would do a manoeuvre before entering.

The second limitation is of technological nature, primarily due to the characteristics of the sensors. The angular focus of the camera limits the possible passages to those visible on the interface. Furthermore, the perception of the laser is limited to an angle of 240°. It is possible, that in follow-up of the trajectory if the wheelchair must move away from the objective, this one can go out of the measurement field of laser sensor. These technological limits can easily be overcome by modifying the used devices (for example by taking a camera with larger focus or by adding a second laser sensor).

One could show here that the complementarity between laser and vision is operative for the control of the smart wheelchair. The deictic control that we conceived and illustrated on the functionality of passing through of narrow passage gives satisfactory results. In order to achieve a command entirely designed on this model it will be necessary for us to develop other functionalities such as direction following, docking and wall following.

References

1. Simpson, R.C., Lopresti, E.F., Cooper, R.A.: How many people would benefit from have smart to wheelchair? Newspaper of rehabilitation Research & Development, vol. 45, No 1, p. 53-72 (2008)
2. Simpson, R.C.: Smart Wheelchairs: With literature review. Newspaper of rehabilitation Research & Development, vol. 42, No 4, p. 423-436 (2005)
3. Connell, J., Violated, P.: Cooperative control of has semi-autonomous mobile robot. International IEEE Conference one Robotics and Automation, 13-18 May 1990, Cincinnati, OH. Piscataway (NJ), pp 1118-21 (1990)
4. Bourhis, G., Pruski, A., Moumen, K., Bop, C.: The V.A.H.M. project (Autonomous vehicle for disabled), European Conference on the Advancement of Rehabilitation Technology, Nov. 5-8 1990, Maastricht, Netherlands, pp. 95-96 (1990)
5. Levine, S.P., Bell, D.A., Jaros, L.A., Simpson, R.C., Korem, Y., Member Senior, IEEE, Borenstein, J., Member, IEEE: The NavChair Assistive Wheelchair Navigation System Transactions one rehabilitation engineering, vol. 7, No 4 (1999)
6. Bourhis, G., Horn, O., Habert, O., Pruski, A.: The VAHM Project: Autonomous Vehicle for People with Motor Disabilities. IEEE Robotics and Automation Magazine, Special Exit one Wheelchairs in Europe, Vol.7, n°1, pp.21-28 (2001)
7. Stefanov, D., Avtanski, A., Well, Z.Z.: A Concept for Control of Indoor-Operated Autonomous Wheelchair. In Advances in Rehabilitation Robotics, Well, Z.Z., Stefanov. (Eds.) LNCIS 306, pp. 253-298, 2004, © Springer-Verlag Berlin Heidelberg (2004)
8. Simpson, R.C., Lopresti, E., Hayashi, S., Nourbakhsh, I., Miller, D.: The Smart Wheelchair Component System. Newspaper of Rehabilitation Research and Development, vol.41, n°3B, pp 429-442 (2004)
9. Nisbet, P.D.: Who' S intelligent? Wheelchair, driver gold both? Conference one Control Applications, Glasgow, Scotland, 18-20 (2002)
10. Bourhis, G., Agostini, Y.: Man-machine cooperation for the control of an intelligent powered wheelchair. Journal of Intelligent and Robotic Systems, Special Issue on "Mobile Robots in Health Care Services", vol.22, p.269-287 (1998)
11. Rao, R.S., Conn, K., Jung, S.H., Katupitiya, J., Kientz, Kumar, T.V., Ostrowski, J., Patel, S., Taylor, C.J.: Human Robot Interaction: Application to Smart Wheelchairs. International Conference one Robotics & Automation, Washington, cd (2002)
12. Crisman, J.D., Cleary, M.E.: Progress one the Deictically Controlled Wheelchair. Assistive Technology and AI, LNAI 1458, pp. 137-149 (1998)
13. Sekimoto, T., Tsubouchi, T., Yuta, S.: A Simple Driving Device for has Vehicle – Implementation and Evaluation –. International conference one Intelligence Robots and Systems, 7-11 (1997)
14. Trahanias, EP., Lourakis, M.I.A., Argyros, A.A., Orphanoudakis, S.C.: Navigational Support for Robotic Wheelchair Platform: An Approach that Combine Vision and Range Sensors. International Conference one Robotics and Automation, Albuquerque, New Mexico City (1997)
15. Leishman, F.: (in french) Approche multimodale vision laser pour la commande déictique d'un fauteuil intelligent. Rapport de fin d'étude, UPVM, Université de Metz, METZ, France, (2008)