Proceedings of the 2006 IEEE/RSJ
International Conference on Intelligent Robots and Systems
October 9 - 15, 2006, Beijing, China

Towards the Adaptation of a Robotic Wheelchair for Cognitive Disabled Children

L. Montesano, J. Minguez, J.M. Alcubierre, Luis Montano
I3A, Dpto. de Informática e Ing. de Sistemas
Universidad de Zaragoza, Spain
{*montesano,jminguez,alcubierre,montano*}*@unizar.es*

Abstract— **In this paper, we describe the adaptation of an autonomous robotic wheelchair for cognitive disabled children. The constraints imposed by these users require developing specific human-machine interfaces adapted to their limitations. In most cases it is necessary to develop additional tools to teach the children the spatial relations between the wheelchair, its motion and the environment. In addition to this, it is important to interact closely with the children and their educators. The paper describes the whole process followed to make the children use the autonomous wheelchair and the lessons learnt during the validation phase with the wheelchair and the children.**

I. Introduction

Robotic wheelchairs are a special type of vehicles whose objective is to improve the quality of life of people with motor disabilities [12]. From a mobile robotic point of view, these devices have been used to test and ameliorate autonomous motion systems. The focus was on improving the quality and autonomy of the motion generated by the system. However, so as to deploy these vehicles in real applications, it is necessary to develop human-robot interfaces to command the wheelchair. Indeed, from the end user perspective, this interface has a decisive impact in the comfort and performance of the navigation task. When the final users are cognitive disabled, the interface has to be designed to fit the users' constraints. Furthermore, in general, it is necessary to develop additional tools to help and teach them to understand the interface and the relation with the wheelchair and its motion. This paper describes the work deployed to make cognitive disabled children use the robotic wheelchair (Figure 1).

The design of an intelligent wheelchair has at least the following functionalities: the robotic hardware platform, the autonomous navigation system and the human machine interface (Figure 2). The starting point of this research was the wheelchair and the navigation system described in [9]. The vehicle is a commercial wheelchair equipped with computers, sensors and actuators. The autonomous motion system drives the vehicle among locations free of collisions. The autonomy of this module is very dependent on the user. In general, as the disease becomes more severe in terms of mobility, the autonomous navigation becomes more relevant. Many of the existing intelligent wheelchairs incorporate these type of motion systems [1], [4], [10], [5]. The advantage of our navigation module is its robustness in complex navigation situations such as narrow doors, populated or cluttered scenarios [8]. This system combined with the developed interface allows cognitive disabled children to use the intelligent wheelchair. The objective of the work presented in this paper is to allow cognitive disabled children to use the intelligent wheelchair.***

Fig. 1. A disabled child drives the vehicle in a populated corridor.

In this context, the final user capabilities determine the type of human machine interface (e.g. voice [7], [6], graphical [4], [10], [7], [6], [13], joystick [4], [7], [5], and eyes or air expulsion [7]). In our case, we collaborate with a school for people with cognitive disabilities. Some of the potential users of the wheelchair in this school have enough visual and speech capabilities, but mobility limitations in their upper extremities. Therefore, we decided to base the interface on these abilities and articulate them with their cognitive limitations.

Keeping in mind the specific needs of the users, our human machine interface has three main components: the order recognition, the order interpreter and the user feedback. The order recognition is an adaptable speech recognition software [2]. This is important since the children present diction problems and speech limitations. The voice commands are very simple such as right, left, far, etc. The order interpreter translates the user's high level commands to specific motion primitives that can be understood by the navigation system. We have tried two different strategies to convert orders in motion. In addition to this, the user needs to understand that a given sequence of orders drives the wheelchair toward a specific place or

1-4244-0259-X/06/$20.00 ©2006 IEEE

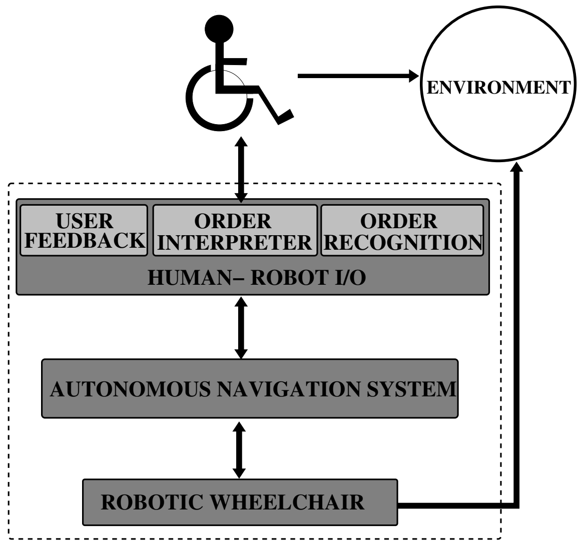

Fig. 2. The navigation system: the robotic platform, the autonomous motion generator and the human-robot interface.

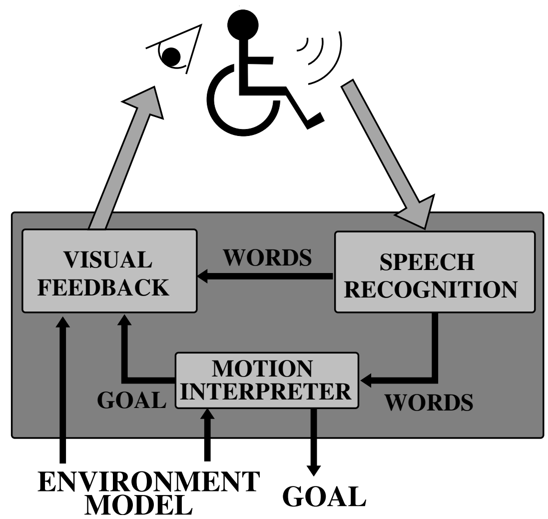

Fig. 3. This figure shows the design of the human machine interface using a voice recognizer (order recognizer) and visual information (user feedback).

direction. For this reason, we have developed cognitive games to teach the children how to use each strategy. Finally, there is a visual interface that gives the user feedback of the system and helps to interpret the speech order sequences.

The educators of the school selected two children to experimentally validate the whole system:

1) Child 1: 15 years old. Paralysis of the lower and upper right extremities. Cerebral ischemia in frontal lobes. Motor aphasia. In his linguistic aptitudes, he shows anomie and his hearing capabilities are also affected. His cognitive capacities correspond to a moderated handicapped child with an intelligence quotient of 44 according to WISC-R[1].
2) Child 2: 10 years old. Spastic paralysis of lower and upper extremities. Visual difficulties. Acceptable short term memory and a good long term one. He is able to receive the most relevant information of the environment and understands simple task instructions. His cognitive capacities, from a qualitative assessment, correspond to a moderated handicapped child.

Both children were able to drive the wheelchair among different rooms in an unknown environment. Despite all the development and validation process was done in tight cooperation with the educators of the children, the experiments revealed many issues that could be improved. We understand that the lessons learnt in this experience could be used as a valuable starting point toward the development of this type of applications.

The paper is organized as follows. Chapter II describes the robotic wheelchair and the autonomous navigation system. In Chapter III, we describe the human-robot interface. Chapter IV describes the validation process from the preparation phase to the final experimentation using the real vehicle. The lessons learnt and future work directions are presented in Chapter V.

[1]Wechsler Intelligence Scale for Children-Revised

II. Robot and Motion System

The vehicle is a robot built from a commercial electric wheelchair. The back wheels work in differential-drive mode and the front wheels are motion-free. We have installed two $Intel$ 800Mhz computers on board, one for control and the other for higher-level purposes. The control PC has installed a real-time operative system (VxWorks). The high level PC has installed Windows and is used to run the motion system and the user interface. Both computers are connected with RS-232 and Ethernet. The main sensor is a planar laser that works at $5Hz$, with a field of view of $180°$ and $0.5°$ resolution (361 points) placed in the frontal part. This sensor provides information about the obstacles in front of the vehicle. The wheelchair is also equipped with a wireless Ethernet card that allows to connect the vehicle to a local network during operation. Furthermore, the wheelchair has a VGA screen and a microphone.

The task of the autonomous navigation system is to drive the vehicle among given locations while avoiding the obstacles gathered by the laser sensor. In order to deal with this problem, the motion system [9] has the following functionalities:

- Model builder: constructs of a model of the environment. This is the representation of the world used as memory in the system.
- Planner: computes the paths to the goal. This is the long term part of the navigation system (create plans).
- Obstacle avoidance: computates the motion free of collisions. This is the short term part (execute the plans).

This motion system has been developed to be robust when facing complex navigation situations. In the context of the wheelchair, these situations are common and appear when crossing a narrow door or when moving in populated, dense and cluttered scenarios. Robustness in this situations is very important since the performance and safety of the user depends on it [11].

III. Human - Machine Interface

In this section we describe the human - machine interface, which is composed by a speech recognition system, a motion interpreter module and a visual interface (Figure 3).

A. Speech Recognition

The speech recognition is in charge of recovering the set of words said by the user. Its basic functional modules are:

- Language models: The language model represents the set of words (vocabulary) and the associated grammar. The system uses an activation word, *Dusila*[2] to filter spurious recognitions. The current motion vocabulary includes the words *Forward, Backward, Right, Left, Far, Medium* and *Close* to indicate the motion direction. The word *Go* starts the motion and the word *Stop* halts the vehicle without any activation word. The user initializes and terminates the whole system with *Start* and *Finish*.
- Acoustic models: So as to adapt the recognition to each individual user, the acoustic models are trained to obtain statistical representations of the Spanish sub-phonemes using a Maximum A Posteriori technique. The advantage of sub-phonemes is that they contain context information. Moreover, they can be adapted to the specific diction of each child [2].
- Speech recognizer: The audio signal is transformed into a set of parameters and variations [3]. Based on these parameters and the acoustic models, a pattern recognition algorithm recovers the set of words said by the user. So as to increase the robustness, the speech recognition system also uses confidence measures to filter spurious recognized words.

B. Motion Interpreter

The role of the motion interpreter is to interpret the sequences of words and convert them into motion directives. In our case, the only information needed by the motion system to drive the vehicle is the goal location. However, the way the sequence of words is interpreted and converted to a goal location leads to different motion strategies. We have developed two strategies that are adapted to the different autonomy of the user:

- Goal-oriented strategy: the sequence of words is interpreted as a way to locate the final position in the space. The goal remains fixed until the vehicle reaches it. For example, if the sequence is <*Dusila, Far, Right, Right*>, the goal location is located at a predefined distance d_{Far} and rotated two times a predefined angle α_{Right} (i.e. $(x_{goal}, y_{goal}) = (d_{Far}\cos(2\alpha_{Right}), d_{Far}\sin(2\alpha_{Right}))$. The goal is given to the motion system that autonomously drives the vehicle until the goal location is reached or the user stops the vehicle through the *Stop* command.
- Steering Wheel strategy: the sequence of commands are interpreted like a steering wheel. The goal is continuously recomputed based on the given sequence to reproduce this behavior. For example, if the user says <*Dusila, Right*> the goal location is placed at a given distance d rotated α in the rigth-hand direction $(x_{goal}, y_{goal}) = (d\cos\alpha, d\sin\alpha)$. However, when the vehicle approaches the goal location, this is periodically recomputed producing a continuous right-hand steering behavior. The motion continues until a new sequence of words arrives to change the direction or to stop the vehicle.

[2]In honor of Livia Drusila, 58 a.c.- 29 d.c. married with Caesar Augustus, founder of the city of Zaragoza, Spain.

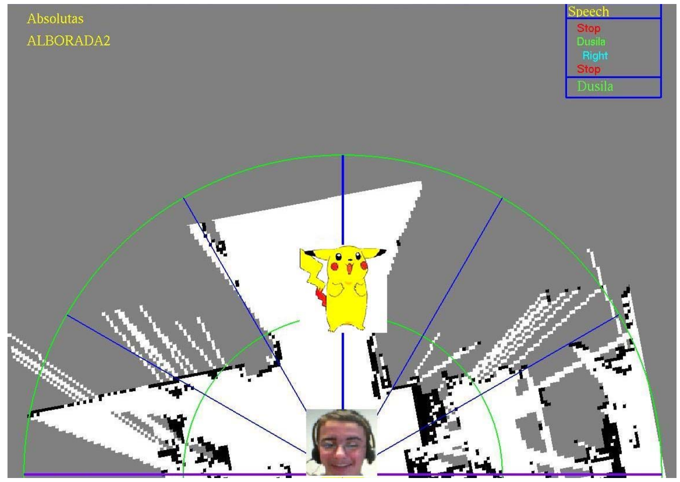

Fig. 4. This figure shows the visual feedback interface of the system.

In the goal oriented motion strategy, the vehicle has full control of the trajectory. Once the user has set the sequence of commands, the wheelchair decides how to reach the final goal. This strategy is an implementation of an *order and forget* system. In the steering wheel strategy, the user interacts more closely with the motion generation, since he has to continuously modify the motion direction. We present the advantages and drawbacks of each strategy through an example in Subsection III-D.

Notice that with both strategies the navigation system is always supervising and is the last responsible of the motion. Thus, obstacle avoidance is guaranteed.

C. Visual Interface

The objective of the output interface is to show all the information required to use the system (Figure 4). The screen displays the 2D map model built by the motion system (constructed online using the laser sensor). This map has to be constructed on line since for realistic operation the scenarios continuously evolve and the locations of obstacles like chairs or tables are unpredictable a priori. The map is rotated in such a way that it is always aligned with the wheelchair forward direction (user). To ease the understanding, a user's photo shows the wheelchair position and the goal location is represented using known characters (in the examples, Pikachu and Ask). The polar grid centered on the vehicle indicates the available goal locations and establishes the link between the words sequences, the goal location and the physical space (map of the scenario). The interface also displays other information like sequences of words recognized by the system for the educator to help the children while starting to use the wheelchair. The size, color and shape of all the interface elements are adapted to the characteristics of each user. In order to make the children understand what the system is doing they also receive auditory feedback.

D. Usage Example

We describe next an example that shows how to manage the wheelchair with both motion interpreters of Section III-B: the goal oriented strategy and the steering wheel one. Let say that the user is facing a door (Figure 4), wants to cross it and continue in a corridor toward the left-hand side.

- Goal-oriented motion: The child using the visual interface map recognizes the wall and the door in front of him. Then, he places the goal (Pikachu) after the door and a little bit on the left-hand side saying the sequence {*Dusila, Medium, Left*}. Pikachu follows the orders and moves on the grid to the medium circle and one sector to the left. When the user says {*Go*}, the vehicle autonomously drives to the final location crossing the door and moving to the left-hand side.
- Steering wheel motion: The user knows that to reach the final goal he has to drive the wheelchair forward to the door and says the word sequence {*Dusila, Forward*}. Autonomously the motion system manages to cross the door, even if it has to change its direction to avoid colliding with the walls. After crossing the door, the user says {*Dusila, Left*} to modify the vehicle direction and turn left. Once the vehicle is aligned with the corridor, the user has to say {*Dusila, Forward*} to move along the corridor.

The previous example illustrates the advantages and disadvantages of each strategy. On one hand, the first motion strategy is more cognitive demanding since the user has to understand the relationship between the map, the wheelchair and the goal location (for this reason we developed some cognitive games that we describe in the next subsection). However, the advantage is that once the goal is located, the user forgets about the motion. On the other hand, in the second approach the user does not utilize many of the information of the interface and needs only to understand the relation of some words with the motion of the wheelchair (user friendly). However, the number of sequences to generate is higher and, in certain cases, may tire the user.

IV. Experience

This section describes the prior work required to prepare the children to drive the vehicle (Subsection IV-A) and the experience with the children and the wheelchair (Subsection IV-B). It is worth to note that all the development and validation was done in tight cooperation with the educators and the psychologist of the school so as to consider the specific needs of each user.

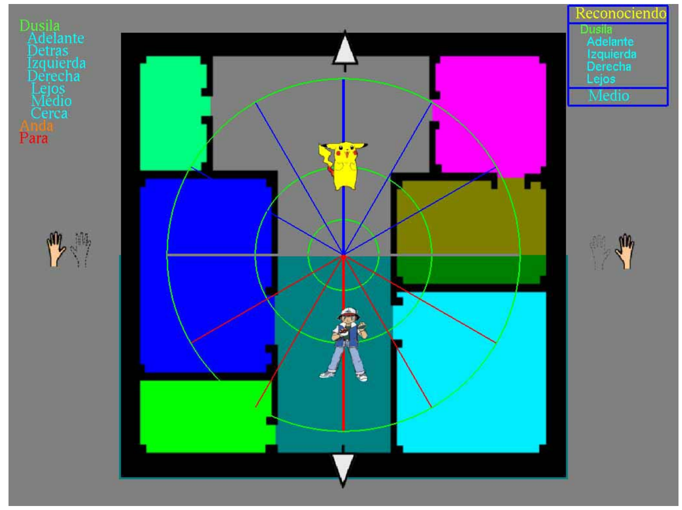

Fig. 5. Screen of Game 3. The background is modifiable to describe the floor.

A. Prior work

As described in Section I, the educators of the school selected two children to participate in this experience, Child 1 and Child 2. Both use standard non-electric wheelchairs and they had never used an electric one before. The first step was to teach the children how to use the system. We have developed some cognitive games with two objectives: (i) to record the voice of the users in order to train the speech recognition system, and (ii) to teach and train the user to understand the interface and its relation with the wheelchair motion (the first two games with both motion interpreters and the last one for the goal-oriented strategy since it involves the map). So as to keep the attention of the children, the games use music and known characters to indicate the locations in the interface and the success or failure in the game.

- Game 1: Relation between voice commands and grid locations. The goal of this game is to learn how voice commands move Pikachu on the polar grid. We place Ask (Pikachu colleague) in the polar grid and the child has to move Pikachu toward Ash using voice commands.
- Game 2: Relation between voice commands and space locations. The goal is to learn how a position on the grid represents a location/direction in the space. The educator selects a location in the polar grid (the child does not see it). Then, he places himself in this location in the space. The child has to be able to devise which location of the grid in the screen corresponds with the location of the educator in the space and move with voice commands the Pikachu to this location in the screen. During the first trials, we painted the polar grid on the floor to help the children to make the connection between the grid and the real world.
- Game 3: Relation between voice commands, space and

map locations. The goal is to learn how one position of Pikachu on the grid represents a location within the map (Figure 5). The educators selects a location on the grid (the child does not see it). Then, he asks the child to place the Picachu ”behind the table”, for example, and helps the child to interpret the map and the physical space until he gets the solution. This game is the more difficult for the children as it requires to link the spatial representation of the map with the real environment. As in the previous game, in the initial stages we painted the polar grid on the floor.

With these *simple* games we fulfilled both objectives facilitating the interaction between the wheelchair and the children. Furthermore, the games were developed in such a way that they are currently used by the educators in the school as part of their program to improve the spatial capabilities of the children (voice - spatial relations as right/left, forward/backward, etc).

B. Wheelchair experience

We tested the wheelchair with Child 1 and Child 2 in our laboratory. The educators described the experience to the children like a big game. All the classroom (around 10 scholars) participated in the visit and they were around in order to make the two children more comfortable.

The trials were deployed in a large office and corridors of the University during rush hour (12am). We installed three cameras to record the global view of the experiment, the child’s face while driving the wheelchair and the driver’s view (*subjective camera*). Additionally, we recorded the data from all the modules of the system (motion system and interface). Finally, the educators interviewed the children in the middle of the experiments. All these data are used to evaluate the system from a psychological and robotic point of view. We describe here the robotic evaluation. We give some hints about the ongoing psychological evaluation currently in Section V.

Figure 6 shows a summary of the experiments. In the first trial we tested the steering wheel strategy. With this strategy, Child 1 was able to get out of the office and took a walk along the corridor. In the first part of the trial (the office, Figure 6(c)) we were all the engineers, the educators and all the classmates. Child 1 managed to get out the office, and drove the wheelchair in the corridor helped by the educator and one of the engineers (Figure 1). After a travel of 50 meters Child 1 decided to come back to the office. The corridor was full of teachers and students of the University (Figure 6(d)). Finally, he came back to the office, crossed the final door (Figure 6(e)) and reached the starting point.

In the second trial, we experienced with Child 2 the goal-oriented strategy, since he is prone to loose attention (Figure 6(f)). Using the wheelchair and only two word sequences Child 2 get out of the office. The navigation system negotiated all the tables, chairs and moving people (Figure 6(g)) and crossed the exit door (Figure 6(h)). The distance traveled was 10 meters.

From the motion system point of view, the performance was very good. The vehicle was safely driven among locations avoiding any static/dynamic obstacles that were negotiated with good safety margins. It is worth to note that the environment was completely unknown, since it contains furniture and people that prevents using a priori maps (see Figure 6(c-h)). Furthermore, the environment continuously evolved (moving people, chairs, doors). This imposed a difficulty in the mapping module that had to be able to build a map of the static parts of the scenario, localize the vehicle within this map and take into account the dynamic obstacles (see Figure 6(b)). In addition to this, there were situations with little space to maneuver such as doors or narrow passages among furniture. The navigation system was able to overcome these situations in a reliable way. Finally, in some cases the children’s orders directed the vehicle toward the walls or other obstacles. To prevent collisions and maintain the vehicle in a safe situation is another advantage of these motion systems.

The main problem encountered during the trials were related to the voice recognition system. In Child 1’s case, the system worked 66% of the times (see Figure 7). There were several factors that degraded the performance of the speech recognition system. In the beginning, Child 1 was quite nervous what modified its diction and make the recognition more difficult. The training was also done in a quiet environment compared to the noisy conditions of the experiment. From the very beginning, Child 1 started to say ”this wheelchair does not understand” or ”this wheelchair is stupid”. However, very soon, Child 1 adapted himself to this inconvenience and stopped the vehicle before retrying new commands (this made him feel safer). Due to this and due to the time thinking in the next word commands, the vehicle was halted many times during the test (see the motion profile bottom of Figure 6(i)). The velocity profile of Figure 6(i) also shows how Child 1 got used to the interface, calmed himself down and was able to return much faster to the initial point after the interview.

In Child 2’s case, he was also nervous, has more severe diction problems and talked very low. Thus, the conditions were very different from the training and the speech recognition performance was very low (under 20% of recognitions). Although he had to repeat the commands several times, the sequence was correct to get out of the office (the educator moved to the place and Child 2 said the word sequence to reach him). This was a clear sign that he understood the games. Once the system recognized the sequence, the wheelchair was autonomously driven out of the room.

Regarding the visual feedback Child 1 did not use it since he was managing the wheelchair in steering wheel strategy. He learnt that the wheelchair understood the orders when it moved. Thus, he preferred to command and stop instead of checking the interface. In the case of Child 2, he did not use it because he has visual problems and the screen was too small for him. The person that really used the screen was the educator that was accompanying the children (this makes them feel safe).

V. Conclusions and Future Work

We have presented in this paper the first steps toward the adaptation of a robotic wheelchair for cognitive disabled

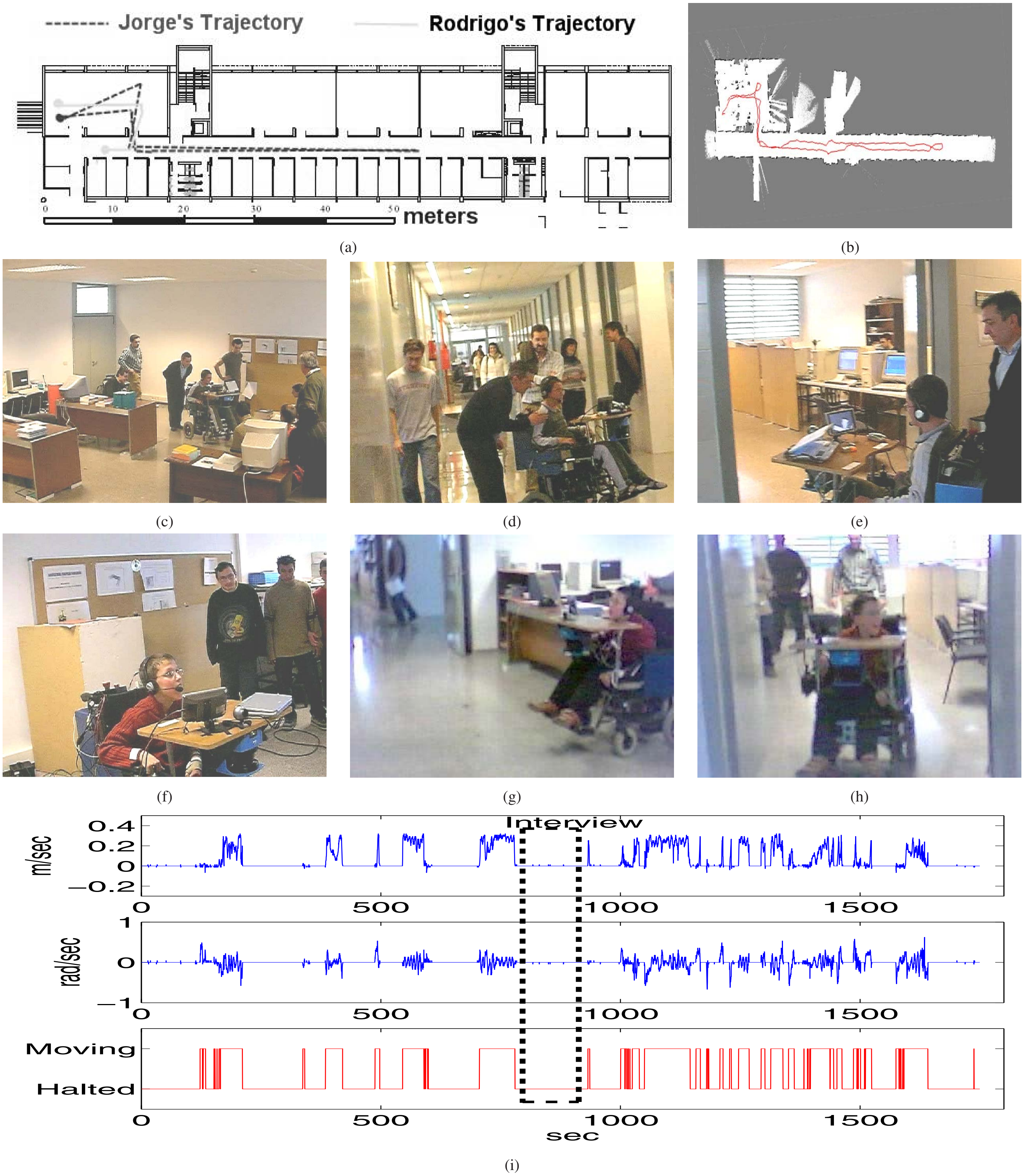

Fig. 6. This figure shows one trial with each of the children. (a) Floor of the University and the travel performed by Child 1 and Child 2. (b) Map model of the scenario constructed by the motion system in trial 1. White is free space, black are static obstacles and gray unknown areas. (c,d,e) Snapshots of the trial 1 and (f,g,h) of trial 2. (i) Translational and rotational velocity profiles of trial 1 and effective motion of the vehicle (moving or halted). The dotted area correspond to the interview we did in the middle of the experiment to relax the children.

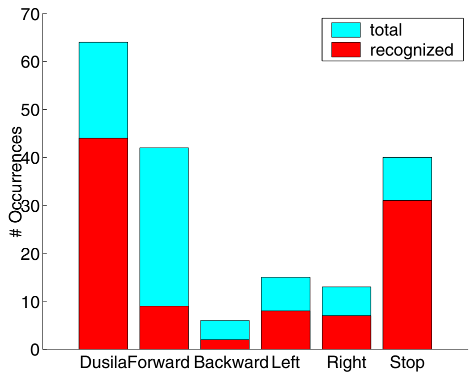

Fig. 7. This figure shows the total number times that the children said word commands and the words recognized and executed by the system. The total number includes also the words that did not agreed with the grammar (the system could recognized the word but the sequence was incorrect).

children. We have briefly described the wheelchair, the human-machine interface and all the tools and work deployed until the first day the children used the robotic wheelchair. Notice that working with cognitive disabled children is far different from working with non-disabled people. As an example, when we started to work with Child 1, the first step with the games was to make him distinguish between left and right.

From our point of view, the performance of the motion system was very good, since all the goal locations were reached without collisions. The experiments revealed that the *Steering wheel* strategy demanded more continuous attention compared to the *Goal-oriented*. However, the latter requires spending time with the games and the visual interface. In both cases, the common direction to improve the system is to add some type of *ad-hoc high-level* primitives like, for example, "approach the wall" or "get out the elevator". These behaviors are easy to obtain in a pre-programmed strategy, but difficult with the given set of orders (specially for disabled children).

The interface has to be improved to feedback the user with the words understood by the system. Although the children learnt on-the-fly strategies to deal with this, the performance could be greatly improved (as the usage of the educators and ourselves suggests). The voice interface was the most penalizing module. We have realized that when dealing with impaired children, there is an important work to show them to correctly use the words. Many times Child 1 was saying the word *Right* without the key word *Dusila* before. In this situation the system ignore the order (but he did not understand why). Furthermore, the speech training has to be done in real situations and not in a controlled environment to capture the real conditions (rapid speech, diction problems, nerves, etc).

Nevertheless, we think that the results are very promising, since the first time the children used the wheelchair, they managed to drive it. Specially, the first child was using it during 26 minutes in an office scenario and through the corridors of the University in rush hour. Both children did not want to stop using the wheelchair.

In summary, we have described the performance of the wheelchair from the robotic and human-machine points of view, and we expect to improve it based on our experience. We understand that the lessons learnt in this experience could be used as a valuable starting point toward the development of this type of applications. In parallel, we are evaluating in cooperation with a psychologist, the psychological response of the user during this experiments based on all the recorded material. This evaluation focuses in the user's perception of the interface and motion quality. From their results, we expect to continue walking toward the development of user centered solutions with focus on cognitive disabled people.

VI. Acknowledgements

We want to thank the *Colegio Público de Educación Especial Alborada*, Zaragoza for the support and specially educators José Pegueiro, José Manuel Marcos and César Canalís for their help, comments and work with the children in all the development of the project. We thank Eduardo Lleida and Oscar Sanz both with the University of Zaragoza, Spain for their help with the speech recognition system. We want to thank Marta Díaz from the Polytechnical University of Catalonia, Spain for her useful comments in the psychological evaluation part of the project. This work has been supported by the Spanish government project MCYT-FEDER DPI2003-7986.

References

[1] G. Bourhis, O. Horn, and O. Habert A. Pruski. An autonomous vehicle for people with motor disabilities. *IEEE Robotics and Automation Magazine*, pages 20–28, March 2001.

[2] R.C. Rose E. Lleida. Utterance verification in continous speech recognition: decoding and training procedures. *IEEE Transactions on Speech and Audio Processing*, 8(2):126–139, 2000.

[3] S. Furui. Speaker-independent isolated word recognition using dynamic features of speech spectrum. *IEEE Transactions on Speech, Audio and Signal Processing*, 34(1):52–59, 1986.

[4] A. Lankenau and T. Rofer. A versatile and safe mobility assistant. *IEEE Robotics and Automation Magazine*, pages 29–37, March 2001.

[5] S. P. Levine, D. A. Bell, L. A. Jaros, R. C. Simpson, Y. Koren, and J. Borenstein. The navchair assistive wheelchair navigation system. *IEEE Transactions on Rehabilitation Engineering*, 4(4):443–451, December 1999.

[6] C. Martens, N. Ruchel, O. Lang, O. Ivlev, and A. Graser. A friend for assisting handicapped people. *IEEE Robotics and Automation Magazine*, pages 57–65, March 2001.

[7] M. Mazo and Research Group of the SIAMO Project. An integral system for assited mobility. *IEEE Robotics and Automation Magazine*, pages 46–56, March 2001.

[8] J. Minguez and L. Montano. Autonomous Sensor-Based Motion Control in Unknown, Dynamic and Troublesome Scenarios. *Robotics and Autonomous Systems*, 52(4), 2005.

[9] L. Montesano, J. Minguez, and L. Montano. Lessons learned in integration for sensor-based robot navigation systems. *International Journal of Advanced Robotic Systems (in press)*, 2006.

[10] E. Prassler, J. Scholz, and P. Fiorini. A robotic wheelchair for crowded public environments. *IEEE Robotics and Automation Magazine*, pages 38–44, March 2001.

[11] N. Storey. *Safety-Critical Computers Systems*. Addison-Wesley, Reading, MA, 1996.

[12] H. A. Yanco. Integrating robotic research: A survey of robotic wheelchair development. In *AAAI Spring Symposium of Integrating Robotic Research*, 1998.

[13] H. A. Yanco. Wheelesley, a robotic wheelchair system: Indoor navigation and user interfaz. pages 256–268. New York Springer, 1998.