Prof. Alain Pruski
LASC
University of Metz, France
alain.pruski@lasc.univ-metz.fr

Trends in smart Wheelchairs

The mobile robotics applications in assistance to the handicapped persons begins in the early 90s. These projects were pretexts in developments of new mobile robot features and an important openings in researches towards original problems created by the man presence. At the end of the 90s, all industrial nations have their projects of automated or robotized wheelchair. In this paper we propose a the state of the art overview of works in the field of intelligent wheelchairs and a personal approach of what should be such a system.

1. Introduction

The handicap which consequence is a reduction of mobility has multiple sources. It has traumatic origins, genetic origins or even psychic origins. Whatever the loss or reduction of mobility origin, the disabled person has not or no more the faculties of movements of a healthy person. The wheelchair constitutes a palliative mechanical system allowing to find a partially autonomy in the movement and so to retrieve an independence and a social activity. The manual wheelchair allows to palliate the incapacities of lower limbs with the conditions that power developed with the upper limbs is sufficient. If residual movements are too weak, in magnitude or in power then only the electric wheelchair may bring a solution. If movements are very weak, of very reduced magnitude, affected by a tremor or even if the person suffers from cognitive troubles, from adaptation or from mental tiredness then a basic electric wheelchair is not a solution to the mobility problem. In the last decade numerous researches was developed in the field of intelligent wheelchairs able of taking into account the various incapacities of persons particularly in the designation of the goal to reach and in the assistance in movements. In this paper we propose a survey of the state of the art of works in the field of intelligent wheelchairs and an approach of what, in our opinion, such a system should be.

2. What is a smart wheelchair ?

2.1. Introduction

The applications of the mobile robotics in wheelchair driving assistance has for origin the beginning of the 90s. These projects were pretexts to the new features development of mobile robots and important openings to original problems of researches due to the man presence. In the end of the 90s, all industrial nations have their projects of automated wheelchairs. Two projects types are developed during this decade: the projects of functional constituents and the integrated platforms. The first category have allowed to integrate on an commercial electric wheelchair, specific characteristics stemming from the mobile robotics field. The detection of obstacles and their avoidance was the main feature studied. We may mention, in a more general way, the sensor-referenced control. The second project category concerns particular functionalities adapted to the handicapped person at the control interface level and at the various features management level. These projects are often a result of European collaborations.

The intelligent wheelchair global architecture is generally constituted of four parts:

- the seat;
- the mobility mechanism;
- the instrumentation;
- the control.

Every part is developed according to the user needs as well as the context of environment in which he has to evolve.

2.2 Smart Wheelchair architecture

2.2.1. The seat.

The handicapped person on wheelchair can feel pain or a discomfort owed either by a particular posture or by a too long local immobility. The seat design has a particular importance, either it is rigid and the person is moved manually by a third person, or it is manually movable by a simple mechanism, or it can be very complex and controlable by the user through a suited interface. In this last case the mechanism looks like a manipulator with several degrees of freedom. The seat can be modified so that the person can lay down, can sit down or can get up. The first two positions allow the person to solve its discomfort problems by a better pressures distribution. The third position allows him/her to reach objects situated in height as a book on a bookshelf or to reach a posture facilitating dialogue with not handicapped persons. This multi-positions seat, complex in term of design, engender constraints on the mobility control which has to take into account the instantaneous position specifically to avoid the fall.

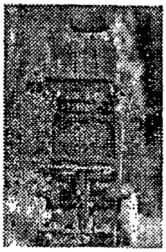

Figure 1. A Multi-positionning wheelchair

2.2.2. The motion mechanism.

The intelligent wheelchairs were developed either by modifying a commercial wheelchair or by an original design. Following our knowledge, only two types of mechanisms of mobility were retained: wheels and hybrid structures, wheels and arm.

2.2.2.1. Systems with wheels

The mechanical architecture and the wheel features (power, guiding wheels, caster) leads towards holonomic or non-holonomic systems. The powered commercial wheelchairs are conceived on the principle of four wheels (rarely three). Generally two of them are power wheels and two others are caster wheels according to a mechanical architecture which looks like mobile robots. The non-holonomic characteristic must be taken into account by the user and by the embarked intelligence. The rotation center is always situated on the axis passing by the power-guiding wheels. Essential difference between wheelchairs, is the position of the power-guiding wheels which are either behind or in front. When the rotation center is situated in front, the space swept by the mechanical structure is reduced in front allowing the user an easier manual control. On the other hand, it turns out that for an automatic control, a center of rotation situated behind is more interesting. The elements of perception which are frequently ultrasonic sensors are situated on the structure and notably in the front. A remote sensing allows an easier control.

The wheel type is an important element that have to be considered in the design of an intelligent wheelchair. The mobile robots are mostly provided with wheels in hard materials with a mechanical characteristic stability (diameters of wheels, distances between wheels) allowing to obtain a location measure by dead reckoning with a relative good precision. For comfort reasons, inflatable tyres are used leading to a lack of mechanical characteristics stability with the negative consequences described above.

It was developed, in Hagen's university in Germany [1], a wheelchair of which main characteristic is the omnidirectionnality assuring to the user a movement flexibility in a constraint environment. Mechanical design is based on a specific wheel use called " Mecanum ". A sub-set of added little wheels with free motion and at 45 ° oriented, is fixed around main wheels controlled independently. A global control according to three degrees of freedom allows to obtain longitudinal movements, transverse movements and rotation movements on a plan (Figure 2.). This technology reaches performances compared to structures based on classic wheels in term of mobility on various types of grounds (stones, PVC, carpet) in various conditions (dry, wet, slippery ground) and on slopes going up to 25 % [2].

Independance Technology Compagny proposes [3] a specific wheelchair with four wheels. A wheelchair control system allows to operate either on four wheels or on two wheels due to a method of stabilization by gyroscope.

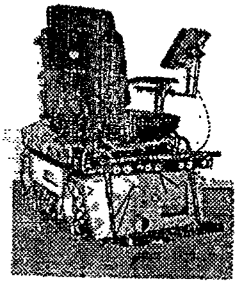

Figure 2.: OMNI, the omnidirectionnal wheelchair

2.2.2.2. Hybrid system

One of the major inconveniences of systems with wheels is their incapacity to surmount obstacles as pavements. An original approach was proposed by the University of Pennsylvania (USA [4][5]) which consists in setting up two manipulators (Figure 3.) with two degrees of freedom on every front sides of the wheelchair. The first consideration which prevailed in the choice of this structure was the security of use and the stability. A structure with wheels is more stable by nature and on the other hand a structure with legs is more adaptative to the ground. The inconvenience of mechanisms with legs is the difficulty for reaching a high power/ mass ratio. Hybrid structure allows to uncouple the system mass and the power needed to cross obstacles. The two arms can be used to push or to open a door or to reach objects.

Figure 3.: hybrid Mechanism of the wheelchair ATW

2.2.3. Sensing system

As a mobile robot, the intelligence of the wheelchair stems partially from the perception ability of the environment and the knowledge of its own state. The sensors used on intelligent wheelchair are identical to those used on autonomous robots, the perception faculties remains the same. Two sensors' categories are used:

- Those which allows to obtain information about the mobile state entering mainly in the position computing;
- Those which allows to obtain information of a higher level on the global or local configuration of the environment.

The first assures the control execution of a mobility task and the second intervene in the definition of the task to be executed. The odometry takes place in the sensors' first category. Encoders placed on wheels allow to deduct the robot position by a rotation measuring. For comfort reasons, wheels are constituted by inflatable tyres which present the inconvenience of an asymmetry between wheels as well as a variation of geometrical characteristics in the time. These problems generate important uncertainties in the position computing. Nevertheless, the odométry is always used as a supplement to the other localization methods. On important distances, as an outside use of the wheelchair, the odométry becomes unusable. In [6][7] the authors propose the use of the Global Satellite Positioning system GPS. This technology, when it is used in differential, allows to reach a precision of 5m what is acceptable on large navigation areas as in a city. If a lesser precision is required, a system GPS mono-receptor allows to reach 100m what is sufficient to be able to join the origin in case of loss of orientation.

Within the framework of the environment perception systems, the ultra-sound waves telemetric sensors are and will remain present on wheelchairs. Obtained precision are weak, variable with regard to the conditions of use and detection are random because dependent on the orientation of obstacles. On the other hand their cost is low which allows to increase the its number in order to increase the volume of information. The majority of the "intelligent" wheelchairs are provided with it.

NAVCHAIR project (figure 4.) [8][9] [10] [11], developed in the University of Michigan in the United States, is a prototype which allows the development of the obstacles avoidance functionality based on data stemming from unltrasonic sensors.

Algorithm VFH and its derived algorithms was implemented on a wheelchair provided with 12 ultrasound sensors. It allow to pass through doors of 80 cms width with 100 % of success for an wheelchair having 63 cms in width. These algorithms were frequently used within the context obstacle avoidance. In the SENARIO project [12] the authors propose a modification by including the kinematic constraints to the algorithm.

The sensors described above assure the obstacle presence detection. This information is taken into account within the context of the prevention of collisions or a localization procedure. One of potential danger for a wheelchair user remain, not the obstacles presence but rather the absence of support of motion. A downward stair or a hole on the way are dangerous and often not visible by the person. In [6] and [7] the authors propose the use of a combined system camera and a sweeping laser to determine the ground variations. This technique is also used to discover natural beacons, corners of walls, the presence of walls, the openings doors which allows to localize the mobile.

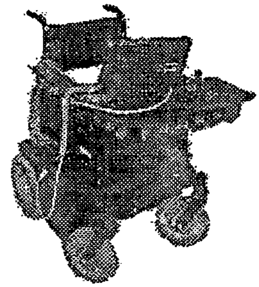

Figure 4 : NAVCHAIR prototype

2.2.4. Controls

Commands constitute the various features which proposes the wheelchair to the user. This aspect of intelligence arises from the available memory and from the processing capacities as well as the possibilities of environment perception. So the user can:

- Control the movements in a manual way by being assisted with the machine in the perception, in surveillance and in obstacle avoidance;
- Be assisted by sensors referenced controls (follow a wall, follow a person, door passage);
- Use a knowledge of the environment or the memory of a realized or learnt road (path planning towards a goal, return backwards).

2.3. Conclusion

The global architecture of an intelligent wheelchair is very close to those of the autonomous mobile robots. Specificities arise from the man presence and from the use of the system by and for the man. This specificity increases constraints notably of security of use, the material cost and the used technology. Numerous developed projects have all original characters but often are connected on certain technological or methodological approaches. Figure 5. summarizes briefly the main characteristics of various developed works.

Project's name	Country	Location sensors	Environment sensors	Functionilties	Objectives	Specificities
Autonomous Vehicle Madaraz	• USA	• Ground marks	• US • Camera	• Planning strategies • Obstacle avoidance	• Carry a person without user help	• One of the first projects
CALL Smart Wheelchair	• UK	• odometry • Ground marks	• Contact sensors • US	• Follow lines on the ground • Wall following • Obstacle avoidance	• Tool for the cognitive, social, perceptual and communicative development	• Reactive architecture
DRIVE ASSISTANT	• Finland		• US	• Obstacle avoidance	• Obstacle avoidance assistant	• Combined man-machine controls
INRO	• Germany	• GPS • Odometry	• camerá • US • laser	• Obstacle avoidance • Group motion • Autonomous return to origin	• Autonomous indoor and outdoor motion	• Centralized location information • Avoid holes
NAVCHAIR	• USA	• Odometry	• US	• Obstacle avoidance	• Obstacle avoidance assistant	• commande partagée homme-machine
OMNI	• Germany • UK • Italy	• Odometry • marques au sol	• US • IR • Contact	• Stored trajectory execution • Retrurn backwards	• Motion assistant	• omnidirectionnal
SENARIO	• Germany • UK • Greece • France	• inclinometer • odométrie	• IR scanning range finder	• Motion learning mode • Autonomous mode • Semi-autonomous mode	• Intelligent Indoor Motion Assistant	• Man-machine responsibility sharing
SPRINT/IMMEDIATE COACH	• France		• US • IR	• Control filtering mode	• Wall following • Obstacle avoidance assistant	
TETRANAUDA	• Spain	• Ground marks	• IR • US • Caméra • Contact sensors	• Path planning • Trajectory following	• Indoor navigation • Minimum effort wheelchair drinving	
VAHM	• France	• Odometry	• US	• Manual mode • Assisted mode • Automatic mode	• Driving assistance	• Advanced man-machine cooperation
WAKAUMI Wheelchair	• Japan	• Ground marks	• IR	• Motion with on/off control	• Trajectory following indoor and outdoor	• Derived from AGV

Figure 5. : Main projects in the smart wheelchairs field

3. Symbiotic Architecture

The approach for which we opted is relatively different from the one that is developed in different projects mentioned above. It consists in performing a symbiosis between the man and the machine in a way that the behavior of the robot is a continuation of the actions of the man and by introducing into the machine functioning parameters and decision-making which are imposed either by the user or by a human expert. Functioning can then be described in a global way by considering the man-machine entity. The proposed architecture is decomposed into three parts: planning, behavior and coordination where the responsible is the man or the machine.

3.1. Human part

Planning is a task which falls totally to the man-user. Its architecture is based on a top-down scheme: planning-perception-action. The planning level consists in determining the areas to cross to go to the goal. It takes implicitly into account, different parameters as the motivation of the movement and the emotion (hope, fear, satisfaction...). The user owns a good knowledge of the environment, the different particularities (danger, constraints, interests...) of passage points he wishes to cross. He owns a memory of facts and inventories of fixtures which is permanently updated. In the case of the known environment he owns a global vision and in the case of an unknown environment he makes decisions which are adequate to him and performs the learning of environments in a automatic way. He possesses a perception of the local environment which he can integrate to his plan in order to make an immediate action. The actions he is going to generate are movements which correspond to instantaneous directions to be followed in regard with the established plan. In fact the user decides on two types of actions: follow a direction and the absence of direction to be followed. These minimal actions allow him at any time to have the mastery of the movement. The machine can not take him this responsibility.
Actions are defined only according to the aspiration of persons and not according the machine potentialities. The person on the wheelchair is not an expert in robotics and any technical consideration have to be evaded. According to the handicap, the description of the direction to be followed can be realized with a rough precision (strong spasticity ...). This aspect must be taken into account in the execution of the movement by the machine.

3.2. Robot part

We propose for the robot part an architecture based on one bottom-up structure. The machine works according to basic behaviors the use of which is managed by a coordinator. A behavior corresponds to the potentialities of reactions of the machine with regard to the perception and to the expected action. The structure of the architecture is a combination between the subsumption architecture defined by R. Brooks [13]) and a classical reactive architecture. We define two types of behavior: innate behavior and adapted behavior.

3.2.1. Innate or generic behavior

The innate behavior which will be describe rather by the term generic behavior defines a movement of the machine the origin of which constitutes a stimuli either stemming external from the environment (presence of an obstacle) or internal (state of the system, the past, the progression ...). In the first case we have a reactive behavior or a reflex behavior and in the

second case we follow a vector defined internally. We consider that the set of movements, except reflexes, may be described by a succession of linear trajectories. The two innate behaviors that we propose Reflex and Vector Following must be compatible and acceptable by the user. Their functioning must be adapted and customizable by the user in order to take into account the emotional aspects (fear, concern, satisfaction) particularly in the distance of approach of an obstacle authorized or the quickness of reaction of the machine to follow a vector. The algorithms performing this behavior decompose the problem into other lower level behaviors. Reflex behavior corresponds to a weighted integration of the angular and linear speed to be imposed to the robot by each sensor of environment perception. A table defined by the user and helped by the robotics expert allows to adapt the reaction of the mobile to every sensor individually [14]. For the Vector Following behavior, the approach is appreciably the same. We decompose into a corresponding set of sub-problems which correspond to different positions and different orientations of the robot according to a base vector. A table defines the behavior of the robot in term of angular speed to be adopted in different cases. This table corresponds to a unfuzzyfication table used with the techniques of fuzzy logic. This method presents the advantage to be compatible with a human representation of a problem. An identical approach might to be adopted in the case of the reflex behavior. For each of these behaviors we perform a regulation to zero of a linear and angular speed.
The two generic behaviors are mutually exclusive which is to say that they cannot be activated at the same time.

3.2.2. Adapted behavior

Adapted or evolved or learnt behavior corresponds to a variety or a class of generic behaviors defined by a set of parameters. Every generic behavior engenders a class of adapted behavior.

3.2.2.1. Behavior based on the Reflex innate behavior

We propose two behaviors based on classes of Reflex Behavior: the reactive avoidance and the free space following. Two groups of information are associated to each of this behaviors: the sphere of influence to the obstacles to be taken into account and the set of the distances to the obstacles perceived by the sensors.

- Reactive Avoidance

Reactive Avoidance Behavior (AVOID) corresponds to a pure Reflex Behavior. It is activated as soon as an obstacle is situated in a zone close to the robot.

- Free Space Following

Free Space Following Behavior (FSF) corresponds also to a pure Reflex Behavior but the sphere of influence of the sensors is more important.

3.2.2.2. Behavior based on the innate Vector Following behavior

This class of behavior based on the parameter setting of the vector that the mobile have to follow and this according to the obstacles location and of internal variables. Currently we have implanted three of this behaviors type but we can notice that this class is very opened.

- Wall Following: the behavior which consists in following a wall and which is divided in two sub-behaviors Left Wall Following (LWF) and the Right Wall Following (RWF) corresponds to follow a vector parallel to the right or left wall according to the behavior to be defined and at a customizable distance of the wall.

- **Direction Following:** Direction Following behavior (DRF) consists in defining the vector to be followed in a centered user frame with the direction to follow as a constraint.

- **Backward:** Backward behavior allows to free the wheelchair when it is blocked by an obstacle ahead. It is essentially used in release maneuvers. Two sub-behaviors are defined Left Backward (LBK) and Right Backward (RBK). In both cases the vector to be followed has an orientation upper to PI / 2 or less then to -PI / 2, a negative linear speed and is situated to the right or to the left behind the user.

- **Stop Behavior:** Stop (STP) is a very important behavior because it defines the immobility of the wheelchair. The vector of control corresponds to the null vector.

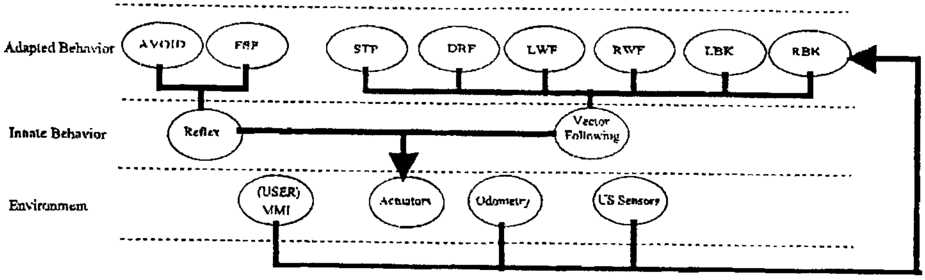

Figure 6. : System Architecture

3.3. Behavior Selection

The approach of command of the wheelchair by behavior requires an adapted software structure. The architecture which we have implemented is totally behavior-based. Our robot works according to a set of behaviors as we have previously described. M. Mataric described exactly the outlines of such an architecture [15] which is based on a modular set of agents executed in a simultaneous way according to a parallel process. This structure, not hierarchical, and distributed in a homogeneous way, is very opened to the removing or to the introduction of additional agent which does not have to disrupt global functioning.
Every behavior assures a mobility of the couple man-robot the best adapted to the environment. In the field of the intelligent wheelchair different projects propose frequently an outfit of commands similar to behaviors defined above but only [16] describes a method of automatic choice of command based on probabilistic information. In our application every Behavior agent is executed in parallel, creating so a competition among them. All the time, every agent delivers controls of speed to respect the behavior which he represents. The key issue consists in performing an arbitrage between different behaviors. The approach which we propose consists in estimating, by every agent, the degree of priority of its command all the time with regard to a preliminary definition of the context in which the behavior must be used. This definition can be imposed by the user in agreement with an expert allowing him so to understand the reactions of the robot because he will have programmed them himself. Employed method uses Case Based Reasoning (CBR) [17]. A base of cases collects a set of generic cases associated to each behavior which contains the state parameters of the environment, the state parameters of the system and the control imposed by the user. The evaluation of the priority of the behavior is performed by a calculation of minimal distance between parameters defining real case and the set of cases of the base connected to the behavior. The agents are organized into a class hierarchy according to the level of the execution priority: the agent STP, the agents which have

inherited of the behavior Reflex then the agents which have inherited of the behavior Followed by Vector (without STP). The agent having the best level of priority in a given class is executed under condition that all other agents of a superior class have a null priority. The details of the CBR methodology are mentioned in [18].

3.4. Method consequence and advantage.

One of first advantages noticed is the simplification of the control of the wheelchair. The person defines the direction he wants to follow without caring about problems inherent to the kinematics of the controlled system. The errors of definition of direction due to the handicap, particularly the spasticity excess, is automatically taken into account. An error of direction definition close to a wall does not lead to a collision. On the other hand a bigger stability is obtained which favors a bigger comfort of movements. Usually, system takes care of the obstacle avoidance, which is the initial function implanted on any intelligent wheelchair. A navigation too close to a wall engenders frequently oscillations which are uncomfortable movements. The use of behavior eliminates this problem. One of the most important advantages concerns the emergence of behavior that constitute the sequences of independent behavior. Two peculiarities notably: automatic operations and reasoned avoidance. This emergent behavior is illustrated in results.
Another advantage results from the modular architecture global. All the agents are independent that is that it is possible to remove or to add one or several agents without disrupting the global functioning of the system. This just like any animal society in which the individuals are born or die without disrupting global functioning. On the other hand the quality of obtained results is a function of the aptness and the capacities of the present individuals at the given moment.

4. Conclusion

This paper objective is to describe the essential elements which define an intelligent wheelchair. Globally we can notice that the major part of developments were a transfer of the know-how of the autonomous mobile robot towards a commercial wheelchair. In our reflexion, we tried to describe a particular approach of an intelligent wheelchair control. Works made in this domain present numerous functions but the choice of their activation is generally under the responsibility of the user what requires the development of a complex interface. We tried to show how a fusion of competence of the man and the machine allows to delegate the choice of the function which has to be activated while staying in agreement with the user.

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