Fuzzy-Based Navigation System of a Powered Wheelchair

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Abstract

This paper reports some projects in the area of "intelligent" powered wheelchairs for disabled people. RobChair, a project running in our Institute, aims to provide the end-user with an easy and safe way to steer a wheelchair equipped with a voice interface. This paper mainly describes the part of the project concerned with local obstacle avoidance strategies used to ensure the safety of the user and to improve the wheelchair mobility. A behaviour-based architecture is proposed for implementing fuzzy reactive navigation.

Introduction

Powered wheelchairs represent the only mean of locomotion used by motor disabled and elderly people with motor impairments. However, people suffering from severe motor impairments, such as paraplegia and tremors find difficult or impossible to steer a standard wheelchair.

The technology used in mobile robots has being transferred to powered wheelchairs aiming to provide these ones with the same degrees of functionality that mobile robots have. However, a wheelchair system is quite different from a mobile robot. First, it is a human-machine shared control system, which means that the control of the wheelchair will be divided between the user and the "intelligent" wheelchair system. This compels to a strong co-operation between these two entities. Second, because there is a human being involved special requirements of safety and comfort (e.g. smooth movements and ergonomics) must be provided. Third, the wheelchair movements must be coherent and inspire confidence to the user. This means the user must feel that the wheelchair is coherently reacting to input commands.

Mechanical structure of a wheelchair must be comfortable enough to provide the user with pleasant travels. To achieve such feature several drawbacks emerge. Typical wheelchairs usually present kinematics constraints due to the complex geometry of the mechanical structure and present poor dead-reckoning capabilities due to problems related with pneumatic tires, slippage and load shifts.

Another problem is the emergence of undesired movements introduced by front castor wheels. These wheels turn impossible to have a straight motion just after a sharp turn. All these drawbacks make, many times, difficult the application of current mobile robot navigational strategies.

Previous Works

Many works are being developed in order to enhance the quality of life for the disabled. In the field of wheelchair rehabilitation technology, efforts have been done to develop strategies of indoor and outdoor navigation. Some projects are concerned with safety requirements and evaluation of risk conditions, other projects are developing local obstacle avoidance and global path planning methods in order to achieve complex manoeuvres. Some other works are concerned with ergonomic aspects and versatile mechanical structures. Prototypes with robotic arms and legs are being developed. And finally, several projects are developing efficient Human-Machine interfaces. In the following of this section we present summarily several projects.

The NavChair project (Bell et al. 1994a) developed at the Michigan University is a semi-autonomous wheelchair concerned with safe travel in cluttered environments, local obstacle avoidance strategies and execution of some tasks such as wall following. The VFH method (Borenstein and Yoren 1991) (relying on sonar information), originally used for mobile robots, is here implemented. This method, which is an efficient method for obstacle avoidance with minimum speed reduction, allows a shared control between the user and the system. The VFH method finds possible directions to follow, and then match the best direction accordingly with the input introduced by the user through a joystick. Nevertheless, this method revealed to have sudden and unpredictable changes in directions, so VFH was modified to slow the wheelchair. Experimental results reached the conclusion that the system was unable to perform a door-passage efficiently. Automatic selection between tasks, such as obstacle avoidance and door-passage, is also being studied. In (Bell et al. 1994b) a new method of automatic mode selection between tasks, so-called, "stimulus response modelling", has been developed. A specific scenario is studied: selection between an obstacle avoidance-behaviour and a door-passage behaviour. The decision is taken based on sensor information but also based upon the behaviour of the user. A new approach of the VFH method was developed, the Minimum VFH (MVFH). This new method provides a variable component autonomy. With high autonomy, the wheelchair remains in obstacle avoidance behaviour, lowering the autonomy the door passage is effected. Experimental results showed that this method provides safe, effective door-passage.

In (Simpson and Levine 1997) an adaptive shared control method of a wheelchair (NavChair) operated by voice is described. The method is based on a probabilistic reasoning construct, known as Bayesian networks (Charniak 1991), to automatically select the most appropriate navigating mode for the wheelchair. Three navigation modes are considered: general obstacle avoidance, door passage and automatic wall following.

SENARIO (Katevas et al. 1997) is a European project under development that supports semi or fully autonomous navigation. In semi-autonomous mode the responsibility of actions is shared between the system and the user. The system accepts typical motion commands through a voice activated or standard joystick interface and supports wheelchair motion with obstacle/collision avoidance features. Fully autonomous mode is a superset of semi-autonomous mode with the additional ability to execute autonomously high level go-to-goal tasks. To guarantee the user safety several types of risk conditions are evaluated: internal risks (sensor failure, communication failure) and external risks (blocking obstacle, stairs). The obstacle avoidance approach, the Active Kinematic Histogram (AKH) is based on the VFH method. The AKH method takes in consideration the constraints applied by peculiarities in the kinematic behaviour of a typical wheelchair. For example, the AKH method aims to minimise the problems related with the two front castor wheels.

The OMNI European project (Borgolte et al. 1995) is concerned with the development of an advanced wheelchair with high manoeuvrability, able to move with three degrees of freedom in a plane, so that any combination of forward, sideways and rotational movements is possible. Current work aims to provide the wheelchair with increasing functionality: go-to-goal tasks at top; and obstacle avoidance and safety behaviours at intermediate levels.

INRO (Shilling et al. 1998) is a wheelchair system with indoor and outdoor navigation capabilities. The wheelchair is equipped with GPS and a dead-reckoning system allowing self-localisation. Sonars are provided for obstacle avoidance and a system consisting of a laser and a CCD camera is used to detect descending stairs.

In (Jarmo et al. 1996) the goal is to design a low cost drive assistant for a wheelchair. The hardware architecture is based on the M3S bus used for interfacing joystick, motor controllers and sonars. A sonar beam pattern corrective horn was developed aiming to remove the sonar side beams.

In (Kollmann et al. 1997) an extension of the party-game algorithm, a technique of adaptive state-space partitioning, is used for autonomous wheelchair navigation. Results proved that this technique is able to navigate a wheelchair under lab environments. In (Yoder, Baumgartner and Skaar 1994) a time-independent extended kalman filter based on odometric and visual information of cues is used to provide precise position estimates in a structured environment. The system is able to track reference paths accurately and smoothly.

In Manus project (Rosier et al. 1996) a robotic arm mounted in a wheelchair is used to handle objects placed at known positions.

RobChair Project: Objectives

RobChair is a project under development that pursues the following goals:

- guarantee the safety of wheelchair users;
- help the users to perform some complex manoeuvres in cluttered environments;
- guarantee a permanent communication between users and remote observers;
- guarantee that users with different impairments can equally control a wheelchair; and
- finally, develop a modular system with autonomous navigation capability.

Safety is a priority requirement of RobChair. This capability should represent the first level of functionality of the wheelchair. In a second level of functionality the system should be able to assist the user in order to make easier the control of the wheelchair. At these two levels of functionality the user and the system share the control. The user has the responsibility of steering the wheelchair and the wheelchair must be capable of providing corrective manoeuvres. The response of the system could be a coherent movement to avoid an obstacle or simply stop the wheelchair. In a third level of functionality it should exist user assistance to complex manoeuvres.

A concrete situation that is being studied in several works, reported in the previous section, is a door-passage. There are two ways to achieve such a task: 1)- the user goes through the door and the wheelchair provides corrective manoeuvres (level two of functionality) - the success of the door-passage depends on the user ability and on the obstacle avoidance method; 2)- the presence of a door is detected and then the position of the door is obtained using environment sensor information or artificial landmarks, and finally a local path planner provides a trajectory to be traced by the system. In the second approach the user can explicitly signal the presence of a door and command the wheelchair to cross the door. This is one of the great advantages of this Human-Machine system; the user represents a cognitive module with full perception capabilities (assuming the user has no mental

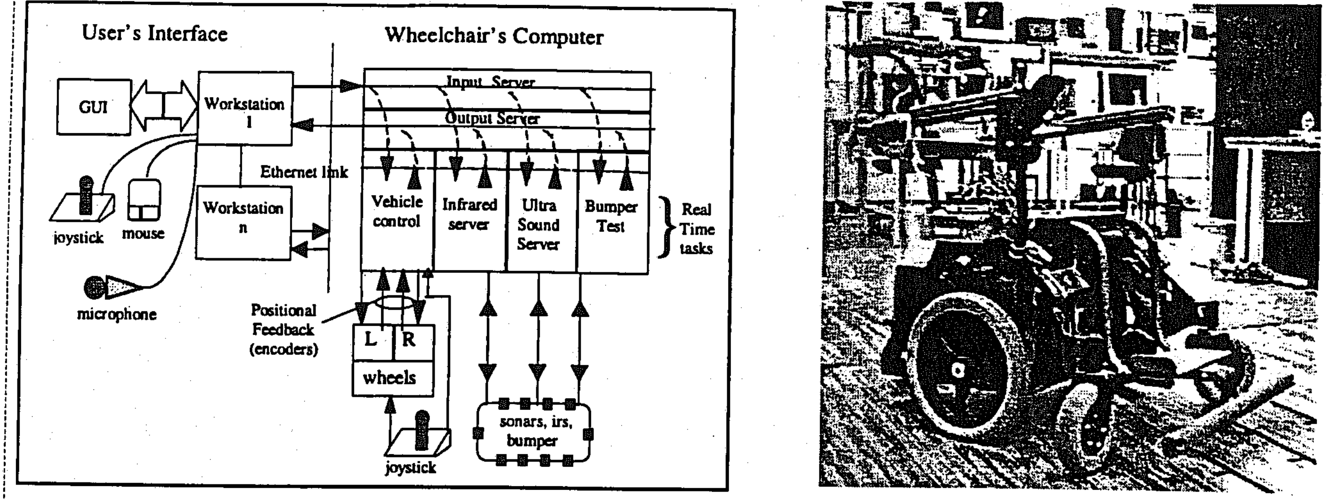

Figure 1: left) Physical devices which compose the system; right) Wheelchair picture.

impairments). In the fourth functional level (top level), a fully autonomous navigation should be achieved. The user would just intervene to introduce *go-to-goal* commands. At this level of functionality the user effort should be reduced to a minimum. On the contrary, the wheelchair would take over the steering actions. The system should have perception and self-localisation capabilities.

System Description

The powered wheelchair[1] is depicted in Figure 1. It is a conventional powered wheelchair with two motorised rear wheels and casters in front. There is also a 5th rear wheel connected to the back of the wheelchair with a damper used for stability. 12 infrared sensors, 4 ultrasonic sensors, a front tactile bumper and optical encoders on wheels compose the sensorial system. Figure 1 shows all the physical devices that compose the system and shows how they interact with each other. The on-board computer system is linked to our ethernet network. By this facility we can remotely control the wheelchair using a mouse, a joystick or voice commands. In the workstation side a 2D/3D GUI (Graphical User Interface) was implemented allowing the real operation of the wheelchair as well as the operation of a corresponding simulation environment (see figure 2). More details about the overall hardware and software architecture are given in (Pires et al. 1997).

Voice HMI

Mechanical input devices, such as joysticks, are very problematic to people who suffer from poor manipulative capability because these devices are as accurate in controlling the wheelchair as the dexterity of the user who operates the device. Using natural language commands, like *move forward* or *move right*, relieves the user from precise motion control of the wheelchair. Each voice command is converted numerically to velocity and steering angle variables by means of a state machine. It is difficult to precisely define wheelchair position and speeds using the set of voice commands represented in Table I. This motivated us to initiate the implementation of a fuzzy voice-activated user interface.

TABLE I: Implemented set of voice commands

Forward	Straight	Fast
Backward	Right	Slow
Stop	Left	Medium

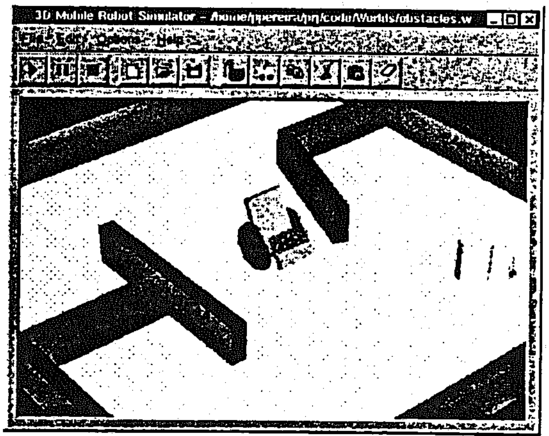

Figure 2: 3D Graphical user interface.

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[1] The wheelchair is a KIPR (KISS Institute for Practical Robotics) product.

In the RobChair system, the user's voice is captured by a head microphone and is processed by a voice recognition system (Dragon Voice Tools). The system has the capability of being trained which leads to more recognition accuracy after being used many times.

Teleoperation Environment

A teleoperation environment was created with several purposes:

- to guarantee a permanent communication between the user and a remote observer;
- to guarantee a permanent monitoring of wheelchair status;
- to provide remote control of the wheelchair to assist the user.

The disabled if in a hospital room or at home on one´s own needs to be permanently observed. An important issue is to guarantee that the user has the means to contact someone if necessary. Another issue is to guarantee remote operation in case the user experiences difficulties to manoeuvre the wheelchair (unable to go through a narrow door or get stuck). The operator has access to a graphical user interface (GUI) which allows a graphical visualisation of the wheelchair (relying on dead reckoning), sensor information and environment map. Obviously teleoperation just relying on dead reckoning is unfeasible. Video cameras would be necessary to accomplish such a task.

Navigation System

The RobChair system has two different modes: an approaching mode and a navigation mode. In the approaching mode the aim is to help the user to approach the wheelchair to a specific place (e.g. a table), performing, for instance, a docking manoeuvre. This mode is in an early stage of development and will not be described here. In the navigation mode we can discern two different approaches: a semi-autonomous navigation and a fully autonomous navigation. In the first approach the system must exhibit obstacle avoidance behaviour capable to assist the user, making wheelchair manoeuvres easier. The second approach consists of an autonomous system capable of performing high level tasks. It obviously uses semi-autonomous navigation capabilities. This paper is concerned essentially with the semi-autonomous navigation mode.

Semi-Autonomous Navigation Based on Fuzzy Behaviours

The proposed navigation mode follows behaviour-based control architecture (Brooks 1986). It consists of three behaviours as shown in figure 3: obstacle avoidance behaviour, collision detection behaviour and contour following behaviour (e.g. wall following). Each one of these behaviours result from a goal driven behaviour, which represents the input command from the user through a joystick or voice, and reactive sensor information from environment stimulus.

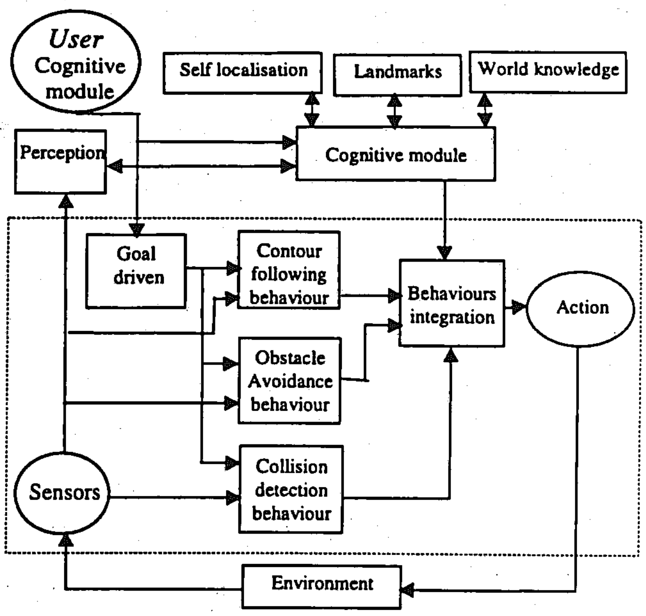

Figure 3: RobChair control architecture.

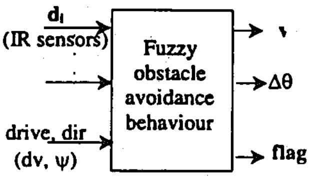

Figure 4: Inputs and outputs of the fuzzy obstacle avoidance behaviour.

The collision detection module uses a simple reflexive stimulus-action behaviour to stop the wheelchair when a dangerous situation is detected. The output of the collision detection behaviour is respectively 1 or 0 if a collision situation is detected or not. If a collision situation is detected the motors are halted.

Fuzzy logic was used in the implementation of the obstacle avoidance and contour following behaviours. This approach has an advantage that it deals with various situations without analytical model of the environment. Fuzzy logic has been widely used in the implementation of mobile robot reactive navigation. As example see (Beom and Cho 1995), (Lin and Wang 1997) and their references. All behaviours are composed of fuzzification, rule base, decision-making, and defuzzification modules. The behaviours integration module (see figure 3) chooses the appropriate behaviour based on the output behaviours. Thus far, we concerning this module did little work.

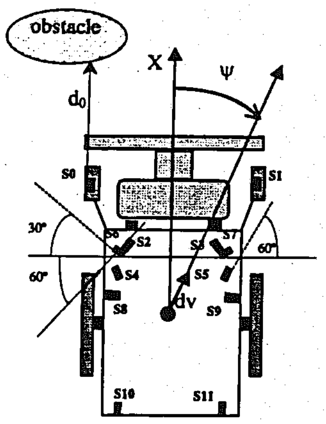

Figure 5: IR sensor arrangement (top view). S_i denotes IR sensor i. ψ denotes the angle between wheelchair heading direction and input direction. d_0 is the distance measured by sensor S_0.

Fuzzification of the Input-Output Variables. A fuzzy operator converts crisp input data into linguistic values. The input linguistic values d_i (i=0,..,11), ψ and vd (see figure 5) are expressed by linguistic values (VN, NR, FR, VF), (NB, NM, NS, ZZ, PS, PM, PB), and (NS, ZZ, PS, PM) respectively (see figures 6 and 7). The output linguistic variables v and $\Delta\theta$ are expressed by the linguistic values (NS, ZZ, PS, PM) and (NB, NM, NS, ZZ, PS, PM, PB) with membership functions having triangular shape. The linguistic terms have the meanings shown in Table II.

TABLE II: Linguistic values.

ZZ: zero	NB: negative big
VN: very near	NM: negative medium
NR:near	NS: negative small
FR: far	PS: positive small
VF: very far	PM: positive medium
	PB: positive big

Rule Base Construction and Defuzzification. The rule base for implementing behaviours is constructed based on human experience. The rule bases for the behaviours are composed of the rules taking the form of IF-THEN statements, as for example:

IF (dv=PM AND ψ=ZZ AND IR(0)=VF AND IR(1)=VF)
THEN (v=PM, $\Delta\theta$=ZZ)

IF (dv=PS AND ψ=ZZ AND IR(0)=VF AND IR(1)=NR)
THEN (v=PS, $\Delta\theta$=NS)

⋮

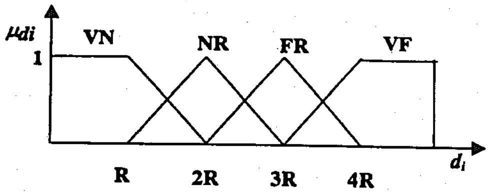

Figure 6: Distance value of the i^{th} sensor.

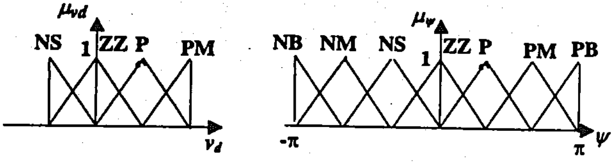

Figure 7: Left)- drive velocity; Right)- desired direction.

where dv and ψ are the input variables, and v and $\Delta\theta$ are the output variables. The defuzification process uses the centre of gravity method.

Contour-Following Behaviour

There are situations for which a contour-following behaviour can enhance the movements of the wheelchair. Using this behaviour, smoother trajectories may emerge than under obstacle avoidance control. For example, the navigation in a curved hallway is clearly a situation in which it is advantageous the use of the contour following. This behaviour is implemented using fuzzy logic similarly as described for the obstacle avoidance behaviour.

Autonomous Navigation

On a second phase of the RobChair project, even without achieving a completely autonomous (without user intervention) navigation, such as *"go to room A"* autonomously, it will be necessary to provide the system with a self-cognitive module. Clearly, this cognitive module should have perception capabilities (e.g. to perceive a door appearance or have a localisation capability) to map sensor information to cognitive attributes. Even a non-fully-autonomous wheelchair must have some capabilities to help the user, for example in the passage through a door. A solution to a *"door passage"* could be based on a reactive behaviour, specific to this task as long as supported with perception, and cognitive capabilities necessary to this end. Certainly, there is a nearly optimum way to pass through a door in what concerns the trajectory to be followed by the wheelchair, relatively to the door. The behaviour must be provided with a set of information that allows it to accomplish this task with efficiency. This control system integrates a cognitive component to plan actions with a behaviour-based reactive actuation (see figure 3).

Experimental Results and Conclusions

Substantial work has been done in several research centers concerning the development of "intelligent" wheelchairs for disabled. However, most of current developments have not proved to be really accepted by disabled people. The wheelchair movements must be coherent and inspire confidence to the user. For this end, further investigation on issues such as safety, ergonomics, friendly and efficient interfaces, mobility improvements and human-machine shared control should be carried out.

A powered wheelchair provided with some intelligence and aiming to assist disabled people has been presented. The Robchair project, under development, aims to provide the end-user with an easy and safe way to steer a wheelchair equipped with a voice interface. As concerns navigation some practical results were already achieved based on purely reactive control. The reactive algorithms that we have implemented so far are memory-less, they do not include past sensor information. Dangerous situations may then occur in environments with thin objects (e.g. table legs), since these objects will not be "seen" at every moment.

As future work we plan to improve the navigation system, namely by incorporating learning and planning capabilities.

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References

Bell, D.A; Borenstein, J.; Levine, S. P.; Koren, Y.; and Jaros, L. 1994a. An Assistive Navigation System for Wheelchairs Based upon Mobile Robot Obstacle Avoidance. In *Proceedings of the IEEE International Conference on Robotics and Automation*, 2018-2022.

Bell, D.A.; Levine, S. P.; and Koren, Y.; Jaros, L. A. and Borenstein, J. 1994b. Design Criteria for Obstacle Avoidance in a Shared-Control System. *RESNA'94 Annual Conference.*

Beom, H. R.; and Cho, H. S. 1995. A Sensor-Based Navigation for a Mobile Robot Using Fuzzy Logic and Reinforcement Learning. *IEEE Transactions on Systems, Man, and Cybernetics*, Vol.25, no. 3, March, 464-477.

Borenstein, J; and Koren, Y. 1991. The Vector Field Histogram - Fast Obstacle Avoidance for Mobile Robots. *IEEE Trans. on Robotics and Automation* 7(3): 278-288.

Borgolte, U.; Hoelper, R.; Hoyer, H.; Reck, H.; Humann, W.; Nedza, J.; Craig, I.; Vallegi, R.; and Sabatini, A.M. 1995. Intelligent Control of a Semi-Autonomous Omnidirectional Wheelchair. In *Proceedings of the 3rd Symposium on Intelligent Robotic Systems*, 113-120.

Brooks, R. A. 1986. A Robust Layered Control System For A Mobile Robot. *The IEEE International Journal of Robotics and Automation* 2(1):14-23.

Jarmo, A.; Olavi, K.; Pentti, M.; Virpi, S.; and Ari, V. 1996. A Drive Assistant for a Wheelchair. In *Proceedings of the CESA'96 IMACS Multiconference, Symposium on Robotics and Cybernetics*, 376-381.

Charniak, E. 1991. Bayesian Netowks without Tears. *AI Magazine*, 12(4): 50-63.

Katevas, N.I.; Sgouros, N.M.; Tzafestas, S.G.; Papakonstantinou, G.; Beattie, P.; Bishop, J.M.; Tsanakas, P.; and Koutsouris, D. 1997. The Autonomous Mobile Robot SENARIO: A Sensor-Aided Intelligent Navigation System for Powered Wheelchairs. *The IEEE International Robotics & Automation Magazine*, Dec. 97, 60-70.

Kollmann, J.; Lankenau, A.; Buhlmeier, A.; Bruckner, B. K.; and Rofer, T. 1997. Navigation of a Kinematically Restricted Wheelchair by the Party-Game Algotithm. *AISB Workshop on Spatial Reasoning in Mobile Robots and Animals.*

Lin, C.; Wang, L., 1997. Intelligent Collision Avoidance by Fuzzy Logic Control. *The International Journal of Robotics and Autonomous Systems* 20(1): 61-83.

Pires, G.; Honório, N.; Lopes, C.; Nunes, U.; and Almeida, A.T. 1997. Autonomous Wheelchair for Disabled People. In *Proceedings of the IEEE International Symposium on Industrial Electronics*, 797-801.

Rosier, J.C.; Driessen, B.J.; Papp, Z.; and Van Woerden, J.A. 1996. MANUS the wheelchair mounted manipulator and future concepts for manipulation for disabled persons. In *Proceedings of the CESA'96 IMACS Multiconference, Symposium on Robotics and Cybernetics*, 238-241.

Schilling, K.; Roth, H.; Lieb, R.; and Stutzle, H. 1998. Sensor supported Driving Aids for Disabled Wheelchair Users. In *Proceedings of the Intelligent Components for Vehicles Conference*, 267-270.

Simpson, R.; and Levine, S. 1997. Adaptive Shared Control of a Smart Wheelchair operated by Voice Control. In *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems*, 622-626.

Yoder, J. D.; Baumgartner, E.; and Skaar, S. B. 1994. Reference Path Description for an Autonomous Powered wheelchair. In *Proceedings of the IEEE Conference on Robotics and Automation*, 2012-2017.

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