Improving the mobility of severely disabled

Pertti Peussa[1], Ari Virtanen[2] and Tiina Johansson[3]

[1,2]VTT Automation,
P.O.Box 13021, FIN-33101 Tampere, FINLAND

[3]Adaptation Training Centre for Disabled,
Launeenkatu 10, FIN-15100 Lahti, FINLAND

[1]*pertti.peussa@vtt.fi*, [2]*ari.virtanen@vtt.fi*, [3]*tiina.johansson@invalidiliitto.fi*

ABSTRACT

A modular mobility aid system is presented, which can be attached to most commercial electric wheelchairs to increase the independence and safety of the wheelchair user. The system consists of falling avoidance, obstacle avoidance, and beaconless navigation functions. Experiences from an evaluation period are presented. Also an idea is presented to combine map information to environmental perceptions in order to provide the wheelchair user a better awareness of his/her whereabouts. The navigation system can also be applied to different mobile robot applications.

1. INTRODUCTION

Safety and independence are very important for elderly people, and especially for the severely disabled. Many of them have to ask help any time they want to move outside their apartment; some need assistance even if they just want to go from one room to another. No one of us would like to be so dependent on other people.

The Adaptation Training Centre for Disabled and VTT Automation joined forces to create more safe and more economical moving aids. The project aimed at modular device prototypes, which could be attached to most commercial electric wheelchairs to enable persons who have not been able to steer a normal electric wheelchair before, to use it independently and safely. One important goal was to initiate industrial interest towards this kind of products, since without good and affordable assistive products no major improvements are possible in the elderly and disabled sector. Important things to consider were easy-to-use, low cost, and easy installation.

The project came up with three main functions: falling Avoidance, obstacle avoidance, and Navigation. To implement these functions, the development of three different but modular devices started. Three separate modules would have made it easy to choose a combination that would best fulfil the individual needs. The only exception to free combinations was, that the navigation module requires also obstacle avoidance module, since the navigation unit needs to know the environmental features, which only the obstacle unit can provide.

VTT delivered a prototype device to the Adaptation Training Centre for Disabled for evaluation about six months ago, and made an other one to further develop navigation methods and Falling&Obstacle avoidance technologies.

2. THE MOBILITY AID MODULES

2.1. *Falling Avoidance*

Falling avoidance is a safety function, that prevents the wheelchair from tumbling down stairs, decks and other similar places. For instance, backing a wheelchair out from an elevator in a confined staircase can be very dangerous. Also the obstacle avoidance system itself can cause problems since it won't "see" any

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descents; if one is passing an obstacle on the left, the wheelchair tends to turn to the right because it only sees a lot of free space there, and not e.g. stairs.

Falling avoidance is an unconditional on/off safety function, which the driver can not overcome it in any way. It is based on six optical sensors: two at the front, two at the back, and one on both side, see Figure 1. The sensors keep watch that there is a surface at a proper level around the wheelchair. If this is not the case, the unit does not allow to steer the wheelchair to that direction.

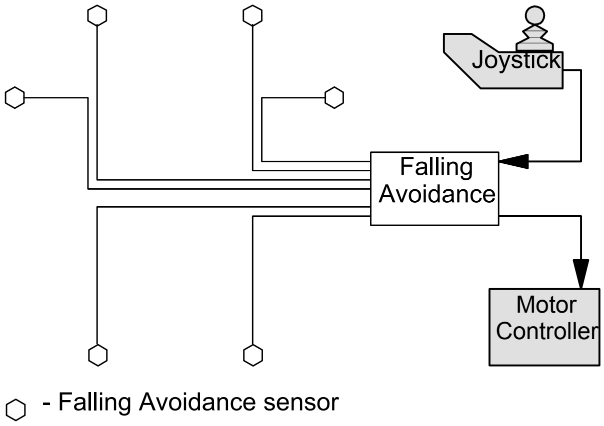

Figure 1. *The basic falling avoidance unit is connected between the joystick, and the motor controller.*

The Unit has been tested with a limited number of sensors. Some further work is still needed to find reliable low-cost sensors, and to find appropriate places for sensor attachments on different wheelchairs. The sensors must "see" far enough from the wheelchair so that there would be enough time to stop even from maximum speed. On the other hand they should also be very reliable despite the fact that they have to be able to detect the floor from an inclined angle, even if it may be very shiny (new, polished floor) or mat (dark carpet). During the project it was found sensible to let the falling avoidance share the same electronics as the obstacle avoidance in the pilot devices.

2.2. Obstacle Avoidance

Obstacle avoidance function is based on a modified potential field method. Thanks to the modifications, it enables driving through doorways, pushing doors open etc. These are simple, but important features, because it would be funny if you could not drive to a table or cupboard with your wheelchair! Potential method itself has many positive features, like that it is reliable and predictable. In many cases it is beneficial that it tends to steer the vehicle in the middle of the free space, which is makes the driving easier in e.g. narrow doorways. The performance of the obstacle avoidance unit can be seen on video clips; look for link at our website at http://www.kautre.aut.vtt.fi/.

The obstacle avoidance unit is attached between the wheelchair joystick, and motor controller, see Figure 2. Its basic function is to modify the analog joystick signals based on the ultrasonic sensor readings. There is also a version which is compatible with a digital wheelchair control bus called the M3S bus. This version can be changed to an other bus called the DX bus. At the moment most of the wheelchair control signals are analog, but the relative amount of wheelchairs utilising serial buses is growing.

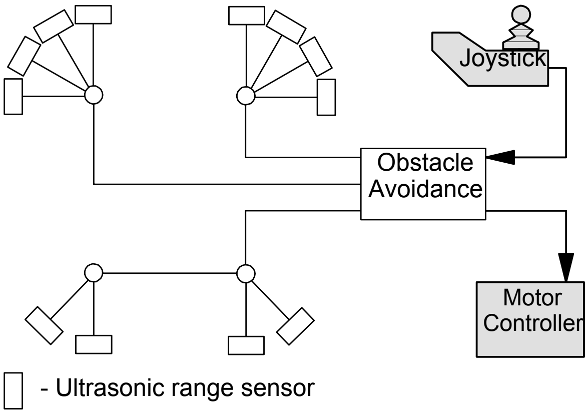

Figure 2. *The obstacle avoidance unit is based on a low-cost 8-bit microcontroller, and 12 low-cost ultrasonic sensors. The analog version is attached between the wheelchair joystick, and motor controller as above. M3S, and DX compatible units are connected to the bus, and then configured to modify the joystick messages accordingly.*

The obstacle avoidance unit does not take over the control from the driver. The unit merely assists the driver by adding a corrective component to the joystick signal. The driver remains the head of the steering all the time. When approaching an obstacle right ahead of the wheelchair, the unit reduces the speed, but continues to approach the obstacle as long as the driver consistently steers towards it. This way one can push doors open, or drive to a table.

The obstacle avoidance software is not limited to ultrasonic sensors. Therefore it is easy to apply also optical sensors, radars, or other technologies. In serial production the size of the unit can be reduced to one fifth of the present size. The component costs are about 330ECU. So far the unit has been successfully tested with three different wheelchairs made by Permobil, Invagear, and Ortoped, see Figure 3. A Finish company is interested in developing this unit into a product.

Figure 3. *Here the obstacle avoidance unit is attached to a standard electric wheelchair. Notice the ultrasonic sensors in the front, and the electronic obstacle avoidance unit at the back. The rear sensors can not be seen from this angle.*

2.2.1. Operating principle. The obstacle avoidance unit is developed to assist persons, who have enough control over their decision making. This means that a wheelchair is not allowed to manoeuvre by itself, and the pilot must have the possibility to collide with anything she/he wants to e.g. to push them aside. obstacle avoidance cannot be bullet proof, because identifying different situations (the pilot wants to collide, or the pilot didn't perceive the obstacle) is impossible. Nevertheless the system must act so clear, that the driver can feel the unit interference in operation. This helps the driver to rely on obstacle avoidance, and also to judge whether the unit is beginning to fail.

Obstacle avoidance algorithm used is based on virtual force field (VFF) -method described by Borenstein and Koren (1991a). Normally in VFF method an obstacle creates virtual pushing force and a target point creates virtual pulling force. These forces are combined and the resultant is considered as a new control of the mobile robot. As the position and heading of the mobile robot are known, the used method needs quite a lot of computing power and one of its disadvantages is that doorways are difficult to pass because of opposite forces. A more developed method is Vector Field Histogram, VFH (Borenstein and Koren 1991b), which is much faster but it also uses position information.

The obstacle avoidance unit does not use wheelchair position, heading, or target information. An obstacle generates a virtual force as in VFF-method. These virtual forces are combined to single force vector, see Figure 4. Sum of this force vector F and the original control vector O is the resultant vector R. In VFF-method R is used as a new control vector. In our method, original control vector O (given by user with a joystick) is turned to the same direction as the resultant vector R. This new control vector O’ is then sent to the motor controller. When O is a zero vector, wheelchair does not move. The user alone controls the speed of the wheelchair. This method allows driving against wall at full speed, if user drives straight toward it. For this reason, one must check directions straight ahead and back separately. If any obstacles are inside the safety limit, wheelchair speed is automatically restricted to a crawling speed. Thus it is still possible to push a doors open or drive to a table, but safely. The algorithm is fast. It takes only about 15 ms to run it with an 8 bit processor.

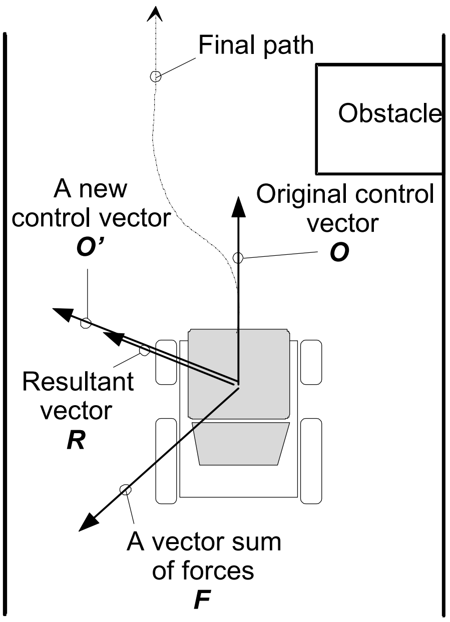

Figure 4. *The vectors of the obstacle avoidance algorithm.*

2.2.2. Encountered problems. The device can not avoid humans, if they happen to move very quickly towards the wheelchair across its route. Usually this is not the case, since those persons usually have their inborn "obstacle avoidance system", and they can dodge the wheelchair far better than the wheelchair could ever bypass them. Some difficulties may arise with standing persons, if they have very soft and thick clothes, which reflect only a very weak ultrasonic echo. Fortunately this is found to be rare during the performance tests that have been carried out. Also obstacles that are above the driver's chest, or less than 10 cm above the floor are not "seen" too well by the sensors, and are therefore not bypassed. This shortcoming will be studied in the future, especially if the pilot devices get good acceptance. One possibility is to use sensors, whose operating principle is other than ultrasonic.

Sometimes the potential field method used by the obstacle avoidance unit may steer the wheelchair in an undesired way, if there is an obstacle on the other side of the path, and a dangerous area like stairs or a street on the other side. Since the obstacle avoidance unit does not ‘see’ any obstacles on the stairs/street side, it tends to drive the wheelchair towards that direction in order to stay away from the obstacle. This is why the augmented joystick signal from the obstacle unit may be passed to falling avoidance unit (if it is attached), which ultimately decides whether it is safe to steer to the current direction.

The obstacle avoidance unit does not get any information whether the wheelchair has really turned to the direction given. This may be problematic, if the driving surface is uneven, or if the castor wheels of the wheelchair have abrupt driving geometry: the augmented signal is not necessarily strong enough to turn the wheelchair even if it has perceived obstacles. Also dead zones in the motor controller add up to the problem. This problem could be overcome by installing wheel encoders, but then the device installation procedure would become more complex. However, this is not a problem, if also the navigation unit is installed. Wheel encoders namely come along with the navigation system, because of the required odometry function.

2.3. Navigation System

The navigation unit is currently under development. It will be able to guide the wheelchair to a given location within a building, or restricted outdoor area. The pilot will not participate to steering, the navigation unit takes care of it, but she/he may interrupt it at any time. The steering signals are sent to the obstacle avoidance unit for further processing just like normal joystick signals. The navigation unit requires three additional sensors: two encoders for odometry, and a low-cost electric compass. Physically the navigation unit means these sensors, and a laptop PC, which contains route planning, and route following software together with maps and landmark information. The laptop is connected to the obstacle avoidance unit by a cable. Figure 5 presents a system which contains all the functions described in this article. At the moment all the maps and landmark information must be imported manually, but it is believed that this could be made easier later.

The starting point for the navigation system design was, that no artificial landmarks or beacons should be used. This dates back to the requirement of maximum independence: the system should operate in any building - not only in user's home. This requirement can also be analysed from the opposite perspective: if the navigation would be based on e.g. radio beacons, it could only be used in areas which are equipped with the specific beacon type. This would limit the user's "independence" only to his or hers own apartment or day centre, since there are no general beacon standards emerging in the foreseen future.

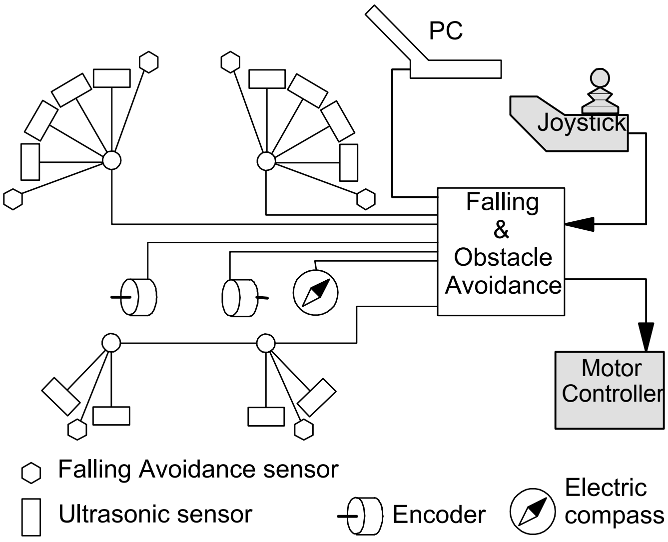

Figure 5. *All the falling avoidance, obstacle avoidance, and navigation hardware installed on a wheelchair. The navigation PC is connected via serial, bidirectional CAN bus.*

The navigation system is not based on accurate positioning or trajectories. It is based on detecting landmarks, and going from one landmark to another, just like we advise someone to e.g. a railway station: "Follow this street about a kilometer, then turn right at the lights. Follow that street about 200 meters, and turn left right after the City Hall. The station is 100 m ahead." These instructions can be elaborated to a more formal state machine representation, where one state could contain e.g. the following statement:

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if travelled_distance = 1000m AND at_traffic_lights = true,
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then Follow_current_street=off; Turn_right_90 = on
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Since the wheelchair is going to move in a rather structured environment, all the landmarks and actions can be described beforehand, like in Table 1.

Table 1. A *structured environment usually contains only a limited number of landmarks, and actions that are appropriate in that context.*

Landmark	**Action**
a wall or large obstacle in front, side distance increased X cm, side distance decreased X cm, a door (when bypassing), a corridor opening (when bypassing), a pillar (when bypassing), a doorway (when entering)	go ahead, turn right, turn left, enter through doorway, follow wall, stop

The obstacle avoidance unit passes all the sensor signals to the navigation system. The navigation PC carries out pattern recognition routines to detect, and classify the landmarks. Since nothing is very precise in the real world, all the information above is handled using fuzzy logic. The pattern recognition is not always an easy task, since the wheelchair may not be moving along straight lines due to the possible obstacles on its route.

Even with fuzzy logic and other precautions, the actions made by the navigation unit would probably cause the wheelchair to hit the walls, to fail to enter doorways, etc. This is another area where the navigation systems relies on the obstacle avoidance unit. As said before, the potential field method tends to keep the wheelchair in the middle of free space, and makes entering through the doorways easier. So when the navigation unit is sending steering actions, they are sent to the obstacle avoidance unit (and these are sent to the falling avoidance unit, if it is installed), which ensures that the wheelchair adapts its actions to the real world, see Figure 6.

3. SOME EXPERIENCES

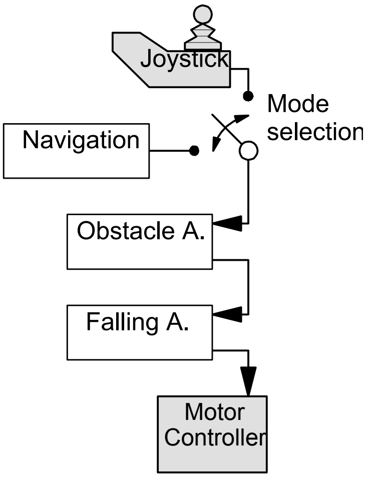

Figure 6. *The flow of the steering signals, when all the modules are installed.*

A prototype device was delivered to the Adaptation Training Centre for Disabled for evaluation about six months ago. It did not have any navigation system, and due to assembly reasons the falling avoidance system was ‘watching’ only backwards. The experiences have been the following:

As with any prototype also this one has not been working properly all the time. Since the evaluation takes place in another city, even very simple malfunctions have caused problems, since repairing them is not possible for others than the ones that have developed the prototype. Most of the problems may be due to the contact problems in the D-connectors used for sensors.

Ultrasonic sensors are not perfect sensors. They may fail in four different ways:

– The obstacle is too small to create any echo strong enough to be detected; e.g. thin wires.

– The shape of the obstacle does not reflect the echo back to the sensors; e.g. a glass door from inclined angle.
– The obstacle absorbs the ultrasonic pulses and only a weak echo is generated; e.g. thick fur coats.
– The obstacle is not within the ultrasonic beam; e.g. an obstacle at the level of the wheelchair pilots face, when the sensors are placed near the floor.

Severely disabled are the main user group. They need very individual seat arrangements, and therefore the sensors should be easily repositioned. This is especially important if the wheelchair is going to be used by an institution, where the user changes frequently.

Many of the disabled who have been involved in the project would like to get this kind of devices to their wheelchair. Naturally they also have certain prejudice towards technical devices. This is why this kind of devices should operate with 101% reliability all the time in all situations. Also the technical support and service must be of high quality. Further development should emphasise the applications for children.

Technology is not the only thing to be developed; also the assisting personnel needs to be trained how to utilise new technology. However, part of the assisting personnel in nurse homes etc. are not technically inclined, and they may consider new devices as a nuisance despite of what the patients think of them. This could even introduce confrontation, if the patient uses his/her improved independence to disagree with personnel.

In all cases this kind of moving aids would provide their users considerably more independence, and experiences that they have succeeded in something they previously felt difficult. Taking care of their own things using their own schedules is an essential part of independence.

4. VR APPLICATIONS

Gundersen et al. (1996) described a wheelchair, where a remote ‘helper’ operator could assist the wheelchair to enter difficult places, like narrow doorways or crowded elevators. Here the suggested approach is different, and is based on providing simple environment information to the wheelchair user to assist her/him to move around more independently.

If we assume that a the described navigation system is widely used, then there are also corresponding maps available. This kind of simplified but structured information itself could be utilised with different VR -interfaces for e.g. training etc. But a wheelchair with prescribed attachment units can combine the map, and real environment information. This could be very useful for persons with degraded cognitive capabilities, since both information formats are very simple. The map could tell that the user is in a lobby, and that the elevators are on the left while the environment information could tell things like “a doorway on the left”, and “obstacle on the right”. This kind of information requires very low bandwidth, and is therefore easier to communicate than e.g. video frames. This approach could provide a simple augmented reality description of the environment to the wheelchair user, and thanks to the simplicity it would be an affordable device. The interface has to be selected according to the functional senses the user has available.

This kind of information could benefit the user in three ways. First it enables her/him to gain a better understanding of hers/his whereabouts, secondly it will activate hers/his mental activity, and last but not least it will make her/him feel more safe. All these are important elements of independence.

The key requirement is that this kind of maps are easily available. The only way this could happen is, that they become part of the information infrastructure of public buildings, which means that they have to be beneficial to all of us - this kind of a system is not going to be established widely only for special groups. The strong investment into telematics research in EU raises hopes that something similar may come up for mass market. There are already experimental telematics services, where a cellular phone user can get his trip planned and guided (text format) automatically from his present location to the destination using all the public multimodal transport services available. Similar services would be welcome to large airports and railway stations as well, and this is where this kind of map/navigation service could gain its commercial feasibility.

5. CONCLUSIONS

This paper presents a set of auxiliary mobility aid device prototypes for electric wheelchairs, and the experiences gained during an evaluation period. The devices may increase the independence and safety of elderly people, and especially those with severe disabilities. The devices combine map, and environmental information which - besides being used for navigation, etc - could also be provided to the wheelchair user via an appropriate interface, if he/she has cognitive difficulties. However, the best way to achieve true progress in the field of assistive technology is that the solutions can be utilised by all of us in a commercially feasible way. Here the hopes lie on the telematic applications for travellers, and on the infrastructure of wireless communications.

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6. REFERENCES

J Borenstein and Y. Koren (1991a), Potential Field Methods and Their Inherent Limitations for Mobile Robot Navigation, *Proc. 1991 IEEE Conf. on Robotics and Automation*, Sacramento, pp. 1398-1404.

J Borenstein and Y. Koren (1991b), The Vector Field Histogram - Fast Obstacle Avoidance for Mobile Robots. *IEEE Trans. on Robotics and Automation*, **7**, 11, pp. 278 - 288.

R. Gundersen, S. Smith and B. Abbott (1996), Applications of virtual reality technology to wheelchair remote steering systems, *Proc. 1st ECDVRAT*, Maidenhead, pp. 47-56.