ABSTRACT

Service robotics is a new, emerging domain in robotics, characterised by enthusiasm, diverseness, and emerging industry. The paper presents modular and interacting obstacle avoidance, and navigation subsystems. The obstacle avoidance system is older, so there are practical experiences of its application to electric wheelchairs, which are explained. Ongoing work with the navigation unit is reviewed.

KEYWORDS: Service robotics, Obstacle avoidance, Components, Ultrasonic

1 INTRODUCTION

There is a new emerging domain in robotics called Service Robotics. It does not deal with product manufacturing, which previously used to be the mainstream in robotics. Since it is a new, developing area, its definition is still vague. However, the questionnaire that is currently being used by the International Federation of Robotics in their yearly study of worldwide robot statistics defines service robot as:

A robot which operates semi or fully autonomously to perform services useful to the well being of humans and equipment, excluding manufacturing operations. [1]

A service robot may be stationary or mobile. The stationary ones often have an arm structure, and they can be used to e.g. refuel cars, wash aeroplanes [2], or to assist handicapped people to eat, wash, and make-up [3]. However, the most common service robot is a mobile one. Typically it is a wheeled, self-powered device, which may sometimes contain an arm and/or an implement. Examples:

- Electrolux is developing a robotic vacuum cleaner,
- Husqvarna has developed an autonomous solar powered lawn mower,
- HelpMate has delivered robot couriers to over 80 hospitals,
- Cybermotion has developed an autonomous 'guard' vehicle,
- Pentagon has been developing supervised, autonomous ground vehicles capable of performing military scout missions, and
- Universities and institutes have developed a vast number of different autonomous designs, etc.
Today every service robot developer is trying to ‘invent the wheel’. Everybody is developing sensor systems, obstacle avoidance systems, navigation systems, etc. The reason is the lack of commercially available choices; in order to get something you have to do it yourself. However, the development is going towards a more organised field formed by specialised subcontractors, more focused research institutes, and collaboration networks. Most service robot manufacturers want to focus on their key expertise - the work process technology - and purchase e.g. the navigation system from a competent partner.

It is also time to assess the commercial possibilities of the various methods and subsystems that universities and research institutes have come up with during the last decade. The authors believe that the obstacle avoidance system described below has potential.

2 OBSTACLE AVOIDANCE METHOD

AGVs and mobile robots need obstacle avoidance systems to avoid unknown obstacles along their routes. Obstacles can be stationary like chairs left in wrong places, or dynamic like humans and other mobile platforms. Obstacles are detected by environment perception sensor systems that vary depending on an application. Ultrasonic or infrared light sensors, laser scanners, microwave radars and machine vision systems are most common solutions.

When an obstacle is detected, one can either carry out path planning to re-route a new safe path, or use real-time algorithms that correct current path on line. The most used method in latter case is based on artificial potential fields presented by Khatib [4]

In Virtual Force Field (VFF) method described by Borenstein and Koren an obstacle creates a virtual pushing force and the target creates a virtual pulling force [5]. These forces are combined and the resultant is considered as the accelerating force acting on the mobile robot. The position and heading of the mobile robot must be known. This method needs quite a lot of computing power when sensor fusion is made through certainty grid [6]. Major problems of this method reported in [7] are difficulties to enter doorways, and oscillations in narrow corridors.

A more developed method is Vector Field Histogram (VFH) [8], which is much faster. In this method a one-dimensional polar histogram is created around the robot. The histogram values are inversely proportional to the distances of the obstacles around the robot. Safe directions are ‘valleys’ on this histogram. The nearest wide enough valley is chosen for the new heading. The travelling speed is also adjusted depending on the distances to the obstacles. More detailed description of this method is given in [8]. The algorithm is used in NavChair [9], which is a wheelchair application like our case.

Obstacle avoidance methods that work on velocity space are presented by Simmons [10] and Feiten et.al. [11]. These methods are based on the fact that a vehicle always moves along circular paths. Taken account the distances to the detected obstacles and the used velocity, a safe curvature can be chosen. Obstacle avoidance methods based on fuzzy logic are presented in [12], [13] [14] and [15]. These methods use simple rules like

<if obstacle is near right then turn left>,
<if obstacle is near left then turn right>. 
The obstacle avoidance algorithm developed by VTT does not use 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 1. 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 (from e.g. a navigation, or a teleoperation system) 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, the vehicle does not move. Compared to the original VFF method, this modification allows passing the doorways easily, because original speed is maintained. The drawback is that driving against wall at full speed is allowed, if user drives straight toward it. For this reason, one must check forward and reverse directions separately. The user sets maximum speed of the vehicle. If any obstacles are inside the safety limit, wheelchair speed is automatically reduced to crawling speed. Thus it is still possible to push doors open or drive to a table, but safely. The algorithm is fast; it takes less than 15 ms to run it with an 8 bit processor.

3 CASE: OBSTACLE AVOIDANCE SYSTEM FOR WHEELCHAIRS

The obstacle avoidance unit has been applied to electric wheelchairs (see Figure 2) to assist individuals, who have poor physical capabilities for wheelchair control, but enough mental capabilities for independent living. The wheelchair should not manoeuvre by itself. The pilot must also have the possibility to collide with anything she/he wants to, for e.g. to push it aside. With these preferences the obstacle avoidance function cannot provide complete protection, 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.
The obstacle avoidance unit is attached between the wheelchair joystick, and motor controller, see Figure 2. Ultrasonic sensors were selected for environment perception due to their low cost. The basic function is to modify the analog joystick signals based on the sensor readings. There is also a version, which is compatible with a digital wheelchair control bus called the M3S bus. At the moment most of the wheelchair control signals are analog, but the proportion of wheelchairs utilising serial buses is growing.

3.1 Obstacle avoidance unit

The unit 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. These are simple, but important features for the appropriateness of the device. Artificial potential field method itself has many positive features, like reliability and predictability. In many cases it is beneficial that it tends to steer the vehicle in the middle of the free space, which makes the driving easier in e.g. narrow doorways. The performance of the obstacle avoidance unit can be seen on video clips; look for a link at our website at http://www.vtt.fi/aut/kau/docs/indexfin.htm.
M3S version was successfully tested in wheelchairs made by Permobil and Kuka. Analog version has been installed to two Ortopedia wheelchairs with Penny&Giles motor controllers, and to one Invagear Garant with Dynamic DX controller.

3.2 Falling avoidance unit

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 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. 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.

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 to provide enough time to stop even from the 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).

3.3 Technical experiences

Since the wheelchairs are differential-driven, steering is based on speed difference between the left and right drive wheels. In wheelchairs the drive wheels can locate either in the front or at the back, and the castor wheels are accordingly at the back or in the front. Collision avoidance seems to work better with wheelchairs having front wheel drive. Castor wheels with abrupt steering geometry tend to require a large moment before they turn, particularly if they are in the front. This causes a large dead zone when turning. Due to the characteristics of the DC-motors, their capability to generate moment is poor at low speeds. This results in situations where the wheelchair doesn’t turn even if an obstacle is right ahead, since the obstacle avoidance function operates in open loop. This feature gets worse on rough surfaces. Adding a velocity feedback from e.g. drive wheels would overcome this nuisance, but then the device would be much more laborious to attach to the wheelchair.

Wheelchair controllers have also large dead zone around the center position of the joystick, and the dead zone is different on both directions. Maximum speed backwards is usually about 2/3 of the maximum forward speed. Due to these nonlinearities, a good overall performance is difficult to achieve when operating in open loop.

Some restrictions come from the physics of ultrasonic technology itself. It is difficult to detect thin shapes like some table legs, or smooth surfaces from an angle like e.g. a glass
door. 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 located at the pilot's knee level, and are therefore not bypassed. These shortcomings will be studied in the future, especially if the pilot devices get good acceptance.

Sometimes the potential field method tends to 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 that way in order to stay away from the detected obstacles. This is why the signal from the obstacle avoidance unit is passed to the falling avoidance unit (see chapter 3.2), which ultimately decides whether it is safe to steer to the current direction.

3.4 Other experiences

One prototype device was delivered to an adaptation training centre for evaluation. As a prototype, some technical malfunctions could not be avoided, but the following focuses on the non-technical issues.

Severely disabled are the main user group, and they often need very individual seat arrangements. 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.

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

4 FURTHER DEVELOPMENT

The essential technologies for all service robots are environment perception technologies and computer science methods, which enable the robot to plan and execute tasks in partially known environment:

- environment representation (unstructured, dynamic)
- environment perception sensing & signal processing methods
- real-time planning of complex missions and services
- navigation, route following, obstacle&falling avoidance, etc. methods
• control approaches (model based, behaviour based, others)
• control architectures for interaction and co-operation
• simulation techniques & environments
• human-robot interface.

The authors are going to focus next on navigation, and its interaction with the collision avoidance.

4.1 Navigation unit

The navigation unit is currently under development. It will be able to guide a mobile device to a given location within a building, or restricted outdoor area. The navigation may be interrupted at any time, whether there is a pilot onboard like with the wheelchair, or the application employs remote supervision. The steering signals from the navigator are sent to the obstacle avoidance unit for further processing.

The navigation unit requires some additional sensors: encoders etc. for odometry and heading. 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, see Figure 4. At the moment all the maps and landmark information must be imported manually, but it is believed that this could be made easier later, see chapter 4.2.

![Figure 4. All the falling avoidance, obstacle avoidance, and navigation hardware. The navigation PC is connected via a serial, bidirectional CAN bus.](image)

The starting point for the navigation system design was, that no artificial landmarks or beacons should be used. This is due to the requirement of maximum independence: the system should operate in any building - not only in a specific facility. And 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. The authors are not aware of any generic beacon standards emerging in the foreseen future.

The navigation system is not based on accurate positioning or trajectories. It is based on error prone odometry, which is refined by detecting natural landmarks, which are known beforehand. The route is defined as landmarks, and actions that take the device 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 the following statement:

\[
\text{if distance} = 1000\text{m AND at_traffic_lights} = \text{true}, \text{then Follow_current_street}=\text{off}; \text{Turn_right_90} = \text{on}
\]

Since the wheelchair is going to move in a rather structured environment, all the landmarks and actions can be described beforehand:

<table>
<thead>
<tr>
<th>landmarks</th>
<th>actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>a wall or large obstacle in front at X m, heading.</td>
<td>follow wall</td>
</tr>
<tr>
<td>a wall or large obstacle in front, side distance increased X cm,</td>
<td>go ahead</td>
</tr>
<tr>
<td>side distance decreased X cm,</td>
<td>turn right</td>
</tr>
<tr>
<td>a door (when bypassing),</td>
<td>turn left</td>
</tr>
<tr>
<td>a corridor opening (when bypassing),</td>
<td>enter through doorway</td>
</tr>
<tr>
<td>a pillar (when bypassing),</td>
<td>stop</td>
</tr>
<tr>
<td>a doorway (when entering)</td>
<td></td>
</tr>
</tbody>
</table>

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 5.

Figure 5. The flow of the steering signal, when all the modules are installed.
4.2 Maps for public buildings

The strong investment into telematics research in EU raises hopes that digital maps would become part of the public information infrastructure of large buildings. Since more and more citizen have e.g. mobile phones, it is natural to assume that the navigatable maps could be available wirelessly to all of us. The service has to be beneficial to all customers, since this kind of system is not going to be established for a special group only.

There are already experimental services, where a mobile phone user can get his city trip planned and guided (at the moment in text format) automatically from his present location to the destination using all the public multimodal transport services available. Similar services would be welcome at large airports, railway stations etc. as well. As a public (maybe fee -based) service to all travellers in need, this kind of map & navigation aid could gain its commercial feasibility.

5 NEW INDUSTRY EMERGING

As said before, every service robot developer today is trying to 'invent the wheel', but a new subsystem industry is beginning to emerge. They are small companies that specialise on navigation, obstacle avoidance, etc. subsystems, and maybe form alliances with manufacturers.

Indications for this kind of development are the plans of a Finnish company Mecastep from Lahti region to focus on service robot subsystems - including an obstacle avoidance system. Also a new VTT spin-off company is soon going to be established at Helsinki region. The company does not have a name yet, but one of their first products is going to be a navigation system for certain off-road machines.

6 SUMMARY

The availability and performance of obstacle avoidance, and navigation system components is very important to the service robotics domain. A modular obstacle avoidance subsystem is introduced, and its application to electric wheelchairs is studied in practice. Ongoing work with a navigation unit is reviewed.

Technology is important for service robotics, but even more important are new ideas. The best applications have not been invented yet. What kind of task or nuisance would you like to give off to a robot?

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REFERENCES


