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A CONCEPT OF SMART WHEELCHAIR

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Abstract: The paper presents the design concept of a smart wheelchair for people with special needs. The first part of the paper explainsreasons for increasing attention in the world for this topicnot only in a context of technical soundness, but enhancement of human-life conditions, too. In the second part of the paper, features of nowadays smart wheelchairs and problems of localization and mapping, which are the main problems in robotics in general, are described. The third part presents thedetails of the novel design of the smart wheelchair, its CAD model and sensor equipment that would be implemented. The idea is to make an advanced wheelchair which will give comfort to a user within the acceptable price range. Further work includes the development of the control system and wiring, the implementation of the obstacle avoidance algorithms, as well as project methodology for efficient customer-oriented wheelchair design and production.
Keywords: smart wheelchair, design, SLAM, sensors, odometry, robotics, human-machine interaction

1. INTRODUCTION

During the past few decades, smart wheelchairs have been the topic that has been receiving increasing attention [1]. This is because of the need for easier wheelchair mobility of an increasing number of handicapped people in the world. In the European Union there are more than two million people with particular disabilities who could benefit from semiautonomous or autonomous wheelchairs. Thus, smart wheelchairs have the potential to improve the quality of life for millions of handicapped persons all over the world. Also, gradual aging of population within prolonged life duration requires an increase of investments in care for elderly and helpless, which manifests in research and development of devices and systems that would enable those people to have more mobility thus making their lives easier.

Wheelchair users exist among all ages. Powered wheelchairs are suitable for people that do not have the strength or the motoric ability to use a manual wheelchair. Also, some people do not have an ability to operate a conventional powered wheelchair, so for those people smart wheelchairs are a perfect way to make their lives easier, and to make them more comfortable while doing their daily routines. Powered wheelchair can be made smart by adding extra equipment on them, such as different types of sensors, software and computer hardware [1]. That extra equipment must be placed in such a way that will not attract too much attention of nearby people or be too disturbing for the user.

For the successful design of smart wheelchairs it is crucial to get and consider users' opinions, and because of different conditions of users, it is important to have an entirely individual approach, and make wheelchairs as suitable as possible for their needs. The goal is that the user and the smart wheelchair are working together, to complement each other. Therefore, smart wheelchairs are excellent test beds for human-machine interaction research. The relationship between a human and a smart wheelchair is just partly similar to, for example, a relationship between a robot and a worker in the factory (interactive human-machine work). Between the smart wheelchair and the user, relationship is much deeper because the human should live with the machine most of the time, the user depends on the machine. Also, during the design process, it is important to consider the opinions of people in close proximity of the user, because the design must be acceptable for the surroundings to make the user feel better and without preconception of other people interacting with the user.

2. FEATURES OF SMART WHEELCHAIRS

Autonomous robotic wheelchairs (ARWs) represent the important class of autonomous mobile robots (AMRs) which are the topics of many researches all over the globe [1]. This is due to the strong need for easier mobility and an easier life for many wheelchair users. The most common way to make motorized wheelchair smart is to add extra equipment on them, as mentioned earlier, like sensors, software and hardware. Smart wheelchairs can be semiautonomous or fully autonomous. Semiautonomous wheelchairs system accepts commands to move in a certain direction, or to take action (e.g. go ahead, move right/left, stop), and realizes the instruction, at the same time preventing risky actions and avoiding obstacles during execution. In semiautonomous mode user can override system actions (e.g. manually move closer to obstacle). In these cases the system applies the minimum speed limit in all instructed commands. In fully autonomous mode, the system accepts all commands like in semiautonomous, and the system first locates itself and then the target position in the environment map. Afterwards, it calculates and executes a path to a specific destination avoiding all obstacles and collisions on the way.

One of the main problems in robotics, as well as with smart vehicles, is localization of the system. The problem is in autonomous mode that the system has to locate itself to be able to do certain tasks: a map is needed for localization, and pose estimation is needed for mapping. The answer to this problem is SLAM – Simultaneous Localization and Mapping. It was originally developed by Durrant-White and Lenard [2], based on earlier work of Smith, Self and Cheeseman [3]. SLAM consists of multiple parts: landmark extraction, data association, state estimation, state update and landmark update. SLAM comprises a range measurement device, odometry data and a mobile robot.

The range measurement device is usually a laser scanner. Those scanners are very precise, efficient and the output does not require much computation. On the other side, they are very expensive, and there is a problem with glass-like surfaces (they give very bad readings). Nowadays, the laser scanners prices are lower than in the past few years, but still quality laser scanners (which can scan and work with data very quickly, work well in a variety of lighting conditions etc.) are still expensive. Other option is an ultrasonic sensor. Ultrasonic sensors generate high frequency sound waves and evaluate the echo which is received back by the sensor. Sensor measures the time interval between sending the signal and receiving the echo, to determine the distance to the object. It is much cheaper compared to laser scanners, but does not give as good measurements.

In general, sensors are needed for SLAM and for obstacle avoidance. Infrared (IR) sensors are always coupled with ultrasonic ones to minimize the risk of a collision, because IR sensors struggle with accurately ranging transparent objects, while ultrasonic sensors struggle with accurately ranging curved objects. The third option is to use vision. The vision gives more information compared to laser and sonar scans, but there can be problems due to changes in light.

SLAM also requires odometry data in order to provide accurate maps. Odometry is the use of the data describing the movement of a system. A sensor used to gather the motion data is the encoder. The encoder is used to measure the wheel rotation of the vehicle and convert it to analog or digital signal. The timing between the laser (or sonar or vision) and odometry data must be right to make sure the laser data will not be outdated if odometry data is retrieved later.

Some of the earliest smart wheelchairs were developed in the 1980s. Over the past few decades, many of the smart wheelchair prototypes were assembled, tested, and documented – such as Rolland, the project from Bremen University who developed four different types of wheelchairs [4], or The Walking Wheelchair, a wheelchair equipped with four legs with wheels at the end of each leg made by University of Castilla [5], and many more [6]. As with most robot applications, smart wheelchairs can implement a wide variety of sensors to successfully implement navigation algorithms. These sensors are strategically selected and mounted on wheelchair for optimal data collection and performance.

Smart wheelchairs also provide great opportunity to research new technical ideas, adaptive and assertive control, new navigational methods and various control methods like a joystick (which is the standard method used in a control motorized wheelchair), control by head movement, speech control, brain-computer interface, eye tracking system and many more.

3. THE CONCEPT OF WHEELCHAIR

This chapter presents the idea for the development of a smart wheelchair [7]. The idea is to make the wheelchair more suitable and comfortable for the most users, taking into account their disabilities, but also not to make it too expensive for regular use. Sensors which are used are: ultrasonic sensors, IR sensors, Kinect and encoders. The reason for using ultrasonic and IR sensors and encoders for odometry is mentioned in the previous chapter. Microsoft Kinect is chosen because it is suitable for 3D mapping of indoor environments and it can provide greater amounts of range data. Kinect has IR range-finder array and RGB camera. It is primarily used for mapping the environment. All the sensors on the wheelchair are presented in Figure 1.

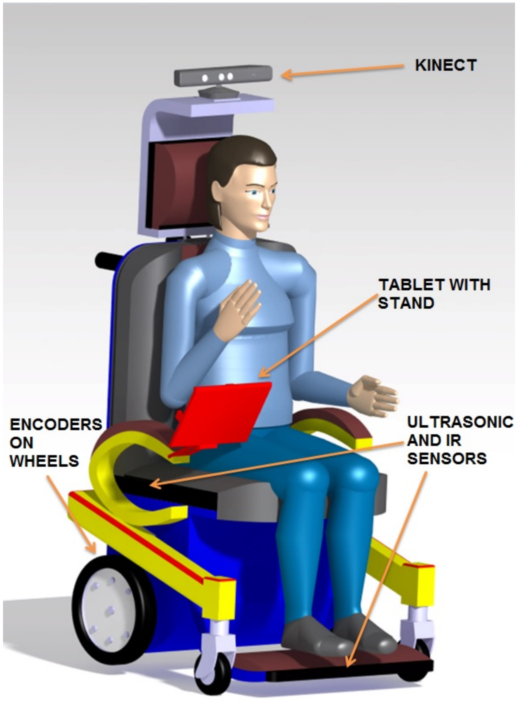

Figure 1 – Design concept

Presented wheelchair is designed in a CAD program, and rendered for the purpose of better visual presentation. SLAM is implemented by Kinect, IR and ultrasonic sensors and encoders (mounted on both rear driving wheels). The designed wheelchair is motorized and powered by an electromotor. Rear wheels are driving, and front wheels are castor wheels which are used for steering.

The user will operate the wheelchair by using a tablet touchscreen, which will give him/her a useful feedback about environment and the wheelchair itself. For that purpose a tablet stand is designed and it is planned to be mounted on the right arm support, slightly angled to provide easier typing on the touchscreen [7]. A stand is designed for 10,1 inch (0,2665 m) tablet because a device of that size will provide easier control and better visibility (Figure 2). Because of the size of the display, the user could easily and more precisely select the desired command and icon. Due to the fact that the wheelchair is controlled by touchscreen, solar reflection could pose a problem, but it would not be such an issue in indoor environments.

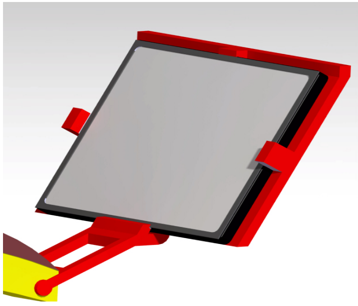

Figure 2 – Tablet and Tablet Stand

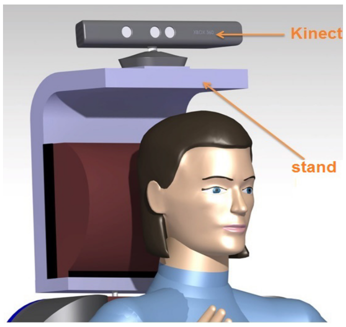

Figure 3– Kinect and Kinect Stand

Problem with the limited area on the upper half of the wheelchair is solved by mounting Kinect stand on the wheelchair headrest, which is perfect because it is out of user's field of vision and Kinect will still be able to collect the data for mapping the environment (Figure 3). Static analysis within the CAD program was used to determine the value of the stand design [7], and the results confirmed that the stand can endure the weight of Kinect.

On the back side of the wheelchair, there are two handles for safety reasons, and a web camera (Figure 4). The wheelchair is motorized, so the use of the handles is just for safety reasons in external conditions. The handles are 10 cm long, so they provide a good grip. The web camera is used to provide the user with visual information of the rear view of the wheelchair. Because of the wheelchair design and conditions of some users, it can be a problem for the user to see what is behind him/her, so it is envisioned that the user can get a live stream from the rear camera on the tablet screen.

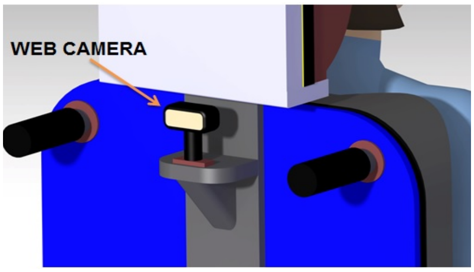

Figure 4 – Back of the wheelchair and web camera

In this design, a great significance is given to users' comfort. Therefore the headrest, armrests, the footrest and the seat are padded. It is envisioned that the wheelchair contains the massage seat, which has a purpose to please the user and reduce back strain, especially because of the long sitting. Massage programs can also be controlled by the tablet.

Considering the sensor technical data and the wheelchair design, positions of ultrasonic sensors and their work radius (in this case the detecting range is from 3 cm to 3 m, and the area of the best performance is at 30 degree angle) are shown in Figure 5. Seven ultrasonic sensors are set in the wheelchair bumper and there are two ultrasonic sensors mounted on both sides beneath the headrest. Ultrasonic sensors work in pair with IR sensors (not presented in the picture).

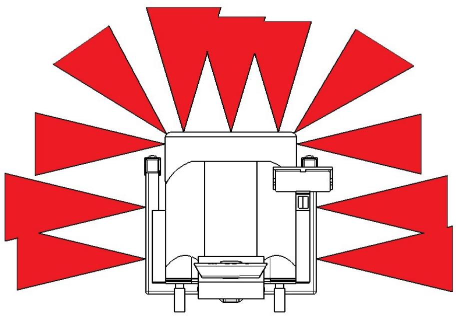

Figure 5 – Positions of ultrasonic sensors with a range up to 3 m and angular coverage of 30 degrees

It is not predicted for the wheelchair to move backwards autonomously. The reason for that is found in research [8]. In that research, the authors counted the number of movements made by one twelve-year-old boy with cerebral palsy and sorted the movements into eight different directions. Statistics show that the forward motion is the most common one and the user uses the forward motion significantly more often than the backward motion. It is predicted that the user can manually go backwards using the picture on the screen provided by the web camera mounted on the back of the wheelchair.

Other ways of controlling the wheelchair are considered, beside the tablet touchscreen. One of them is using an eye tracking system (such as Quick Glance 3 [9]). System tracks user's eyes and moves the cursor depending on which way the user looked. It is observed that it will be very useful for people with tetraplegia who cannot move anything but their heads. Another way of controlling the wheelchair is with smart glove (such as Peregrine [10]). Peregrine has 18 Touch Points and 3 Activator Pads, which give the user more than 30 instantly-accessible actions. It would be a perfect substitute for the joystick because it would give users more freedom and more options to control the wheelchair and it is a more natural way for people who find controlling with joystick hard because of their motoric disabilities.

Described concept of smart wheelchair is applicable to all users that have enough motor skills to control it using the tablet. Also, concept is applicable to users with quadriplegia, paraplegia, cerebral paralysis or other neuromuscular diseases. Depending on the individual state of persons, the wheelchairs can be adapted to the users with additional equipment (e.g. eye tracking device).

Table 1 shows the approximate price of the extra equipment. This does not include prices of the assembly, the software or the parts which would enable a wireless connection of all elements of the wheelchair. For better insight into the overall price of the final product, the real model of the wheelchair is chosen [11], which is capable for implementation of the described concept. The wheelchair is equipped with padded armrests, headrest and seat, which is in accordance with the described model of the wheelchair. The headrest is elevated so it is possible to mount a stand for Kinect. On the sides of the wheelchair, there is plenty of room for the sensor placement, as is on the bumper, so with small modifications the entire sensor montage should be possible. The joystick should be removed from the right armrest so the tablet stand could be mounted on it. The price of such real, basic wheelchair is 1200 USD, so the total price would be approximately 2200 USD for the enhanced (smart) model.

Table 1–Approximate price of the extra equipment

Element	Amount	Unit price, USD	Total price, USD
Kinect	1	100	100
Ultrasonic sensor	11	15	165
IR sensor	12	9,95	119,4
Tablet	1	300	300
Tablet stand	1	50	50
Kinect stand	1	70	70
Web camera	1	40	40
Encoder	2	70	140
Total	30	654,95	984,4

4. CONCLUSION

Nowadays there are many smart wheelchair projects, mostly at universities all over the world. They all encounter the same problems like localization and making the design more adaptable for users. Because of different conditions of users, there is not one particular type of wheelchair that will fit all persons. Also, there are problems with localization of the system and avoiding static and dynamic obstacles. This presents a problem in robotics in general. In this project, a great significance is given to user comfort (padded seat, armrest, footrest and headrest), and it tries to provide the best solution considering the price and acceptability of the design to the user and also to the other people in the user's surroundings. According to this, the concept of the advance wheelchair has been developed costing as low as approximately 985 USD just for the extra equipment, and approximately 2200 USD for the sensors and the model of the wheelchair chosen from the market. Before the realization, it is necessary to work further on the development of the control hardware and software and wiring, and it is important to develop the project methodology which would enable efficient customer-oriented design and production of such advanced wheelchair. Additionally, there are new technologies developed every day, which could be used to control the wheelchair, some arising from the gaming industry (like Peregrine or Quick Glance 3) or neuroscience (wireless brain scanning and imaging). Furthermore, the system similar to the one used in smart wheelchairs can be implemented in hospital beds or carts used for bringing medication to patients or to transport patients to medical examinations and tests within hospitals (especially patients in quarantine, with the purpose of protecting the staff and other patients).

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