IMPLEMETING AUTONOMOUS OBSTACLE AVOIDANCE ON WHEELCHAIRS: DOES IT TRULY BENEFIT WHEELCHAIR USERS?

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By

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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According to the Centers of Disease Control and Protection, 11.7% of American adults in 2019 had mobility issues, including serious issues with walking or climbing up stairs (Center for Disease Control and Prevention, 2019). The percentage of adults who have mobility issues jumps to 35% for persons who are 70 and a majority for those aged 85 and up according to Ellen Frieberger, Cornel Christian Sieber, and Robert Kob (Freiberger et. al., 2020). For these elderly individuals, moving around in a wheelchair may be difficult unless the wheelchair can be moved with a controller. Even in this case, however, a person may accidentally crash a wheelchair into an obstacle, preventing the wheelchair from moving like its supposed to and potentially frustrating the wheelchair user.

In terms of controlling a wheelchair, solutions to prevent it from crashing have been around as far back as 2001 when Hideo Kitagawa, Tsunemitsu Kobayashi, Tatsuya Beppu, and Kazuhiko Terashima (2002) made and tested a wheelchair that used sensors to apply resistance on the joystick that controlled the wheelchair's movement in the direction of the obstacle. Since then, autonomous obstacle avoidance, where an object automatically avoids an obstacle that it would otherwise collide with, has become increasingly popular in usage with applications ranging from guidance for piloting a vehicle (Han, J. et al., 2020) to its deployment in assisting disabled individuals with movement (Joshi et al., 2020).

The STS thesis focuses on trying to determine the impact of implementing autonomous obstacle avoidance for wheelchairs on wheelchair users. Through determining this impact, the STS thesis also seeks to determine if implementing autonomous obstacle avoidance for wheelchairs is beneficial to wheelchair users. I will use the Social Construction of Technology (SCOT) framework pioneered by Trevor Pinch and Wiebe Bijker (Bijker et al, 1999) to help prove the thesis by determining what effects the various stakeholders of a wheelchair that uses

autonomous obstacle avoidance will have on the final product and if those interests can mesh in a way that allows for this product to be beneficial for wheelchair users. Based on this paper, more research could be done into developing a wheelchair that can autonomously avoid obstacles in order to develop one for commercial sale. In addition, this paper can help shed more light on the strengths and weaknesses of autonomous obstacle avoidance as a whole along with highlighting some areas that autonomous obstacle avoidance can really excel.

THE EFFECT OF IMPLEMENTING AUTONOMOUS OBSTACLE AVOIDANCE FOR WHEELCHAIRS ON USERS

BENEFITS OF AUTONOMOUS OBSTACLE AVOIDANCE

Implementing autonomous obstacle avoidance for wheelchairs can have various benefits for wheelchair users. For instance, utilizing autonomous obstacle avoidance for wheelchairs could make life for individuals using the technology easier by preventing crashes in a cluttered environment that may otherwise be difficult for someone to navigate, similar to how autonomous obstacle avoidance for a drone would work (Lee et. al, 2020). This not only helps with keeping the wheelchair user safe but it also helps to prevent potential damage to the wheelchair. Another benefit is that an autonomous wheelchair could be used to use improve its efficiency when traveling (Parikh et al., 2007). This is because wheelchair users may lack the motor skills to move around an area due to a motor disability such as cerebral palsy or because the space is simply tight or hard to navigate when in a wheelchair (Parikh et al., 2007). Around 2 – 3 % of Americans with disabilities have more than 1 disability (Baron, 2022), however that number has

likely increased as the average life expectancy of Americans has increased from 76.75 to 79.11 years from 2000 to 2023 (U.S. life expectancy, n.d), reflecting that the population is growing older and is more predisposition to having multiple disabilities. Given this, having a wheelchair with autonomous obstacle avoidance can help a wheelchair user become more independent when moving around since they will not only be safer but they will also have an easier time moving around since the wheelchair will avoid any obstacles that it may otherwise collide with. In addition, wheelchair users who have issues navigating with a wheelchair on their own would get the most benefit from the addition of autonomous obstacle avoidance to wheelchairs. This is backed up by Linda Fehr, W. Edwin Langbein, and Steven B. Skaar who state that around half of patients who cannot control a power wheelchair by conventional methods would benefit from an autonomous navigation system (Fehr et al., 2000).

DRAWBACKS TO AUTONOMOUS OBSTACLE AVOIDANCE

While autonomous obstacle avoidance has the potential to be extremely beneficial to those with cognitive issues that may affect their motor skills, there are some drawbacks that may need to be considered. A map of these drawbacks is illustrated in Figure 1 below.

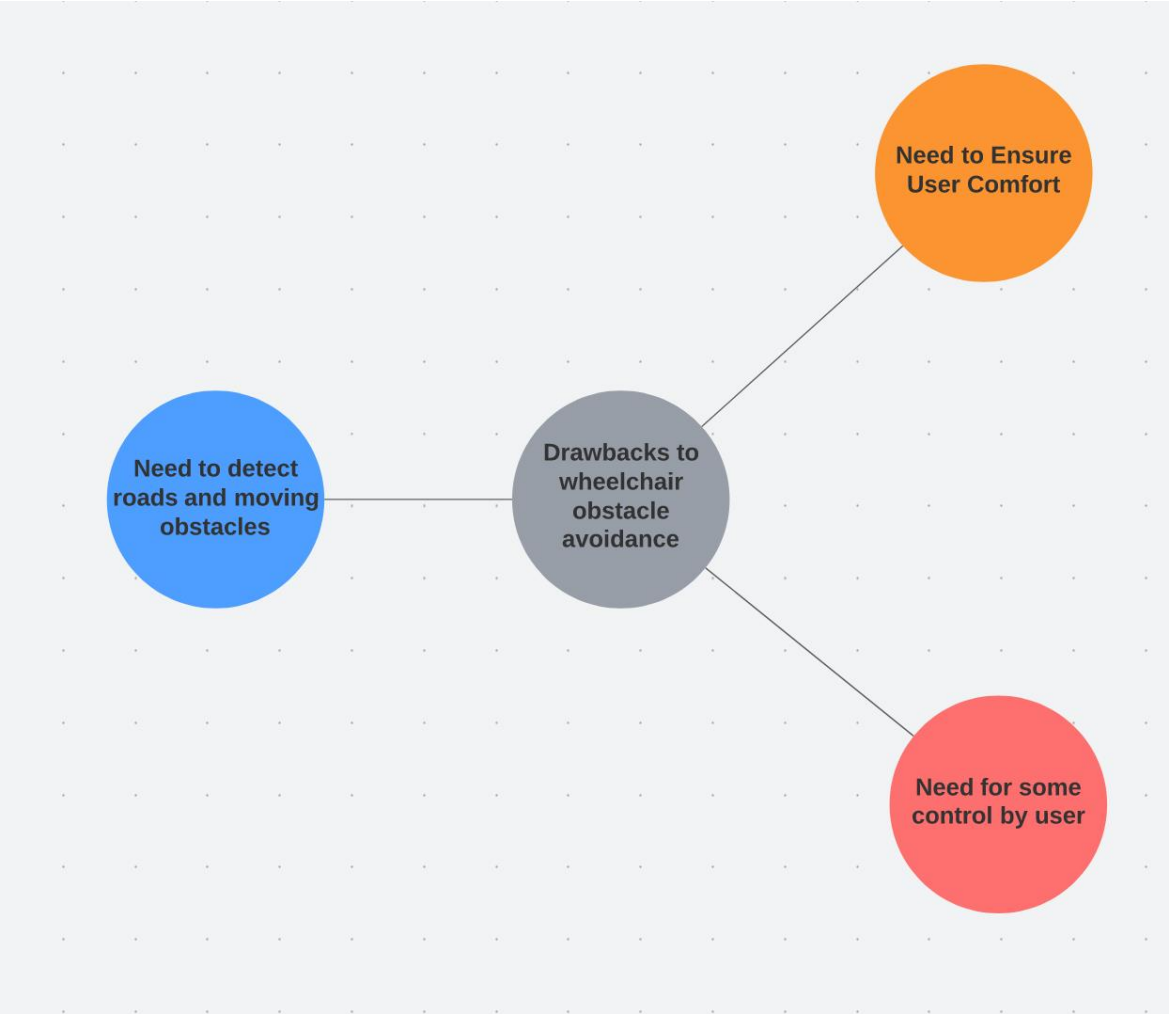

Figure 1: Illustration of the potential drawbacks for wheelchair obstacle avoidance. These include the need to detect roads moving obstacles, the need for some user control, and the need to ensure user comfort (Parikh et al, 2007; Chadha, 2023).

Need to Detect Roads and Moving Obstacles

One potential issue with autonomous obstacle avoidance is that it would need to detect roads. According to the National Highway Traffic Safety Administration, there were 42,915 deaths occurred in 2022 because of motor vehicle crashes, a 10.5% increase in the death rate from 2020 (NHTSA, 2022). Since roads have become increasingly dangerous, it is important for any wheelchair that autonomously avoids obstacles to treat roads differently than normal sidewalks. For example, while a wheelchair should be allowed to move on a road without the obstacle avoidance interfering assuming the wheelchair user intends to cross it, the obstacle avoidance algorithm should not treat a road as space that the wheelchair should go to when avoiding obstacles since the wheelchair may inevitably get in the way of an incoming vehicle. On the topic of motor vehicles, another potential issue for a wheelchair that utilizes autonomous obstacle avoidance is how it will handle moving vehicles such as people or motor vehicles. If a motor vehicle is approaching, the wheelchair will need to a good job moving out of the vehicle's way instead of directly away from the vehicle but in its path. As for other moving objects such as people and animals, it is important to consider how the wheelchair will move to accommodate for them. For example, if a person approaches, one needs to consider if the wheelchair should move in the opposite direction of the person or out of the way, meaning left or right relative to the person approaching.

Need for User Control

One of the most important aspects of a wheelchair that utilizes autonomous obstacle avoidance is to have a switch that lets the wheelchair user turn the obstacle avoidance off. If

someone wanted to talk to the person in the wheelchair, it would be annoying to the wheelchair user if their chair automatically moved away from the person. If a wheelchair user got annoyed by the wheelchair's obstacle avoidance and would prefer to control the wheelchair on their own, they should have the option to do so. In addition, the user should be able to directly control the wheelchair outside of those moments where the obstacle avoidance happens (Röfer, Lankenau, 2000). Without the ability for manual control along with autonomous obstacle avoidance, the wheelchair user will still have difficulty getting around since there is no way to move the wheelchair otherwise.

Ensuring User Comfort

One other issue to consider that may be overlooked is ensuring the wheelchair user is comfortable. This involves the user being comfortable when the wheelchair is changing its direction of movement while avoiding an obstacle along with the speed at which it performs this. Ensuring that the manual control of the wheelchair is also imperative for making sure the wheelchair user is comfortable outside of when the autonomous obstacle avoidance algorithm is at work (Kitagawa et. al., 2002). In addition, it is important to consider that wheelchair users may get more frustrated with the autonomous obstacle avoidance when it doesn't work correctly since the wheelchair user does not have direct control over this algorithm (Parikh, S. P. et al., 2007). Preventing this frustration ties back to the idea that maintaining user control over the wheelchair is necessary for designing one. Ensuring that the user is physically comfortable moving in the wheelchair while also not being annoyed with the autonomous obstacle avoidance is important when considering if implementing autonomous obstacle avoidance on a wheelchair will benefit wheelchair users.

EXAMPLES OF AUTONOMOUS OBSTACLE AVOIDANCE FOR WHEELCHAIRS THAT HAVE BEEN TESTED

Despite the potential drawbacks associated with autonomous obstacle avoidance and wheelchairs, this technology has already been considered and tested in ways that address the potential drawbacks. For instance, back in 2000 researchers Thomas Röfer and Axel Lankenau (2000) explored the operation of a semi-automatic wheelchair that can switch between autonomous and manual control, which was implemented successfully. This research addresses the need for an autonomous wheelchair that can successfully switch between autonomous and manual control in order to give the wheelchair user some control. In addition, researchers Sarangi P. Parikh, Valdir Grassi Jr, Vijay Kumar, and Jun Okamoto Jr. (2007) were able to create a wheelchair that can compute its path of travel, allow for human input into the wheelchair's control, and includes IR proximity sensors and a laser scanner to help detect obstacles that should be avoided. In addition, through their tests, they found that participants felt in control when the wheelchair had semi autonomy, meaning that it utilized both autonomous and manual control (Parikh et al., 2007). This experiment not only address the need for autonomous and manual control but it also addresses the need for user comfort since participants do not feel frustrated with the shared autonomy. As for ensuring that the wheelchair is physically comfortable, researchers Rafael Morales, Vicente Feliu-Batlle, and Antonio Gonzalez-Rodriguez (2010) were able to develop a staircase-climbing wheelchair that was able to generate a trajectory of movement to avoid obstacles while ensuring user comfort thanks to the help of kinematic models and its ability to adapt to the environment. While a kinematic model would not be necessary for the wheelchair proposed in this paper due to it not having the need to climb

steps, the ability for a wheelchair to adapt to the environment to ensure the comfort of the wheelchair user is important to note.

While the examples of research above focus on wheelchairs with shared autonomy between the user and the autonomous obstacle avoidance algorithm and the user experience of those wheelchairs, research has been done to determine how an autonomous wheelchair would perform in an urban environment and around moving obstacles. For the urban environment, Shun Niijimaa, Yoko Sasaki and Hiroshi Mizoguchia (2019)found that wheelchairs with autonomous obstacle avoidance could learn to obey traffic signs and avoid pedestrians in Japan. This wheelchair could also detect roads and used a 3D map and navigation map to navigate the environment, however the wheelchair could not deal with extremely large maps. Having a wheelchair with a 3D map that can detect roads not only helps to make the wheelchair safer since it can gain the ability to avoid a road once it recognizes it, but it could also allow the wheelchair to take note of the signs in the area and potentially act upon them. As for the detection of moving obstacles, researchers Chao Wang, Alexey S. Matveev, Andrey V. Savkin, Tuan Nghia Nguyen, and Hung T. Nguyen (2013) developed an electric-powered wheelchair that used a navigation algorithm which allowed it to avoid moving obstacles by approximating their relative positions. These two examples help illustrate that a wheelchair that implements autonomous obstacle avoidance can not only handle navigating in an urban environment but it can also detect moving obstacles thanks to approximating the moving obstacle's position. In addition, an override functionality can be added to turn the wheelchair's autonomous obstacle avoidance off when the wheelchair user does not want to avoid people for example. This could be added in the form of an on/off switch o0r a button to press.

BALANCING THE INTERESTS OF VARIOUS STAKEHOLDERS

One key factor to understanding if implementing autonomous obstacle avoidance for wheelchairs will benefit wheelchair users is understanding how the interests of the potential stakeholders interact with the engineer through the development of a wheelchair that utilizes autonomous obstacle avoidance. This can be done using the Social Construction of Technology (SCOT) framework by Trevor Pinch and Wiebe Bijker (Bijker et al., 1987; Bijker & Pinch, 1984; Kline & Pinch, 1999). Figure 2 illustrates these relationships relative to the engineer.

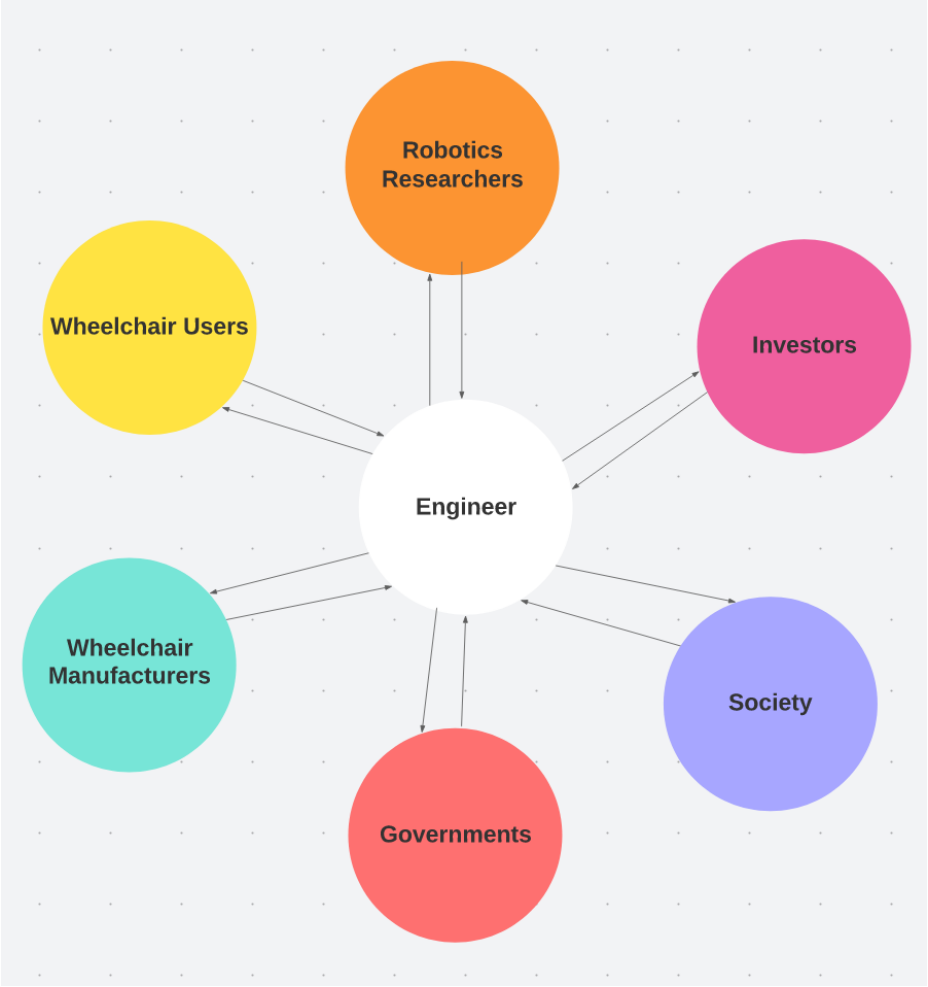

Figure 2: SCOT framework for a wheelchair that implements obstacle avoidance. The engineer is at the center of the model to act as a mediator between the various parties of interest (Chadha, 2022).

Wheelchair Users

For wheelchair users, their vested interest is in making sure that the wheelchair will allow them to go about their daily life in an easier way than wheelchairs without autonomous obstacle avoidance. One key component of this is making sure that the user is comfortable both physically and mentally since a physically strained or frustrating ride will not make a wheelchair attractive, even if it does autonomously avoid obstacles (Parikh, et al., 2007). Some other wheelchair users will need to consider are the portability and cost of the wheelchair ("Ultimate Guide to Buying a Wheelchair", n.d.). These two are especially important to consider when making a wheelchair with autonomous obstacle avoidance since wheelchairs with this capability will need sensors, a motor, and wires so that the wheelchair can detect obstacles and act based on what is detected. This will not only significantly increase the wheelchair's cost but it will also make the wheelchair harder to transport since it will likely be bulkier. Based on this, wheelchair users will want the engineer to make the wheelchair as compact and inexpensive as possible after all of the necessary features for safety and comfort are accounted for.

Robotics Researchers

Robotics researchers will have similar concerns to wheelchair users with regards to safety and cost, however their interest will be more focused on the technology of the wheelchair. This could involve patenting software that is used on wheelchairs, thereby increasing the cost of any wheelchairs that are dependent on the software. In addition, researchers may be focused on advancing the field, so they would have an interest in pushing new software for wheelchairs. Therefore, robotics researchers will want engineers to implement the technology on wheelchairs

so that it can be further improved upon, but at the potential cost of researchers patenting what they develop.

Investors and Manufacturers

The investors for a wheelchair with autonomous obstacle avoidance have one primary goal: to make money off of their investment. This rings true for wheelchair manufacturers as well, however they may be more concerned with the availability of parts since they have to make and sell multiple models once a successful prototype is developed. One conflict that they may have with robotics researchers is that if the technology that was developed by the researchers gets patented by them, then it becomes more expensive as a result. While this can get passed down to consumers to an extent, they will not accept all of the extra cost on their own. Based on this, they will want engineers to develop a wheelchair to be as inexpensive as possible while also, in the case of the wheelchair manufacturer, be relatively simple to put together.

Society and Government

For society at large, the main concern involves how the wheelchair will benefit everyone along with any ethical concerns. If wheelchair users become more independent with this wheelchair than that would cause the quality of life of everyone to increase. As for ethical concerns, society would not want anyone to be harmed in the development of a wheelchair with autonomous obstacle avoidance and some people would want the parts for the wheelchair along with its production to be eco-friendly. As for the government, they theoretically will have similar interests to society since that is who elects government officials. In addition, if the technology

benefits society enough, the government can act as an investor to the autonomous wheelchair that expects the return on investment being the benefit to society that results from the technology being developed and successfully implemented. The government and society's interests could conflict with manufacturers and investors who expect and ROI since they would like to maximize profits, even if that would not lead to the greatest societal benefit. Based on these factors, these parties will want the engineer to develop the wheelchair so that it's production is eco-friendly, and that it is affordable for wheelchair users so that the benefit for everyone is tangible.

Can These Interests Coexist

While many of these parties have similar interests, whether they can coexist comes down to the cost of producing the autonomous wheelchair and how much of a profit researchers, manufacturers, and investors want to make from the wheelchair. A wheelchair that implements autonomous obstacle avoidance can be made cheaply depending on the sensors used, but as more features are added, some of which may be necessary to ensure the safety or comfort of a wheelchair user, costs go up. In addition, if someone decides to put a patent on a piece of technology or a wheelchair that uses a form of autonomous obstacle avoidance to detect objects, costs will rise for wheelchair users, meaning that the technology will not prevalent among wheelchair users. So, despite the autonomous obstacle avoidance for wheelchairs being beneficial to wheelchair users, at the moment costs of the various parts and features may be too expensive for most wheelchair users to afford.

FUTURE IMPLICATIONS OF AUTONOMOUS OBSTACLE AVOIDANCE FOR WHEELCHAIRS

While the cost of making a wheelchair that uses autonomous obstacle avoidance with all of the features necessary to be safe and comfortable for wheelchair users may be high at the moment, in the future these costs will likely shrink as motors and sensors shrink, making the possibility of an autonomous wheelchair real. For future work, one could look into ways to make a wheelchair with autonomous obstacle avoidance affordable without compromising any of the necessary features for safety or comfort. In addition, one could also investigate other ways that autonomous obstacle avoidance may benefit people with motor or cognitive disabilities since this seems to be the group that benefitted the most from implementing autonomous obstacle avoidance for wheelchairs.

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