Affordable Smart Wheelchair

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Figure 1: A prototype of our Affordable Smart Wheelchair

Figure 2: ROS Based wheelchair prototype

ABSTRACT

Power wheelchairs (PW) are an example of an assistive technology in that they are used to increase, maintain, or improve the functional capabilities of persons with disabilities [6]. As seen in [5] [3], the commercially available products do not provide any assistance beyond enhanced mobility. Furthermore, existing PW research fails at comprehensively noting an individual's challenges, such as navigating through narrow passages or fixing their broken wheelchairs. Instead, they focus mostly on novel interaction methods such as BCI, head and gaze control [9] [15]. In this paper, we explore these individual needs and show that PWs have the novel potential to become a smart wheelchair at an affordable price. Our research follows the double diamond (DD) process [2] and relies on the

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Wheelchair; Autonomous; Navigation; Disabilities; Power Wheelchair; Smart Wheelchair; Participatory Design; Double Diamond; Accessible Technology; Assistive Technology; Mobility

participatory design (PD) methodology [7], which addresses all stakeholders involved. Namely, we consider individuals with wheelchairs, the assistive technology research community, and the PW industry. For further insight we also contacted medical doctors, healthcare professionals, and non-profit organizations. We spent time getting to know these communities through interviews, surveys, demonstrations, and continuous user inputs, aligning our work to the PD tools. We found that individuals using wheelchairs overall desire safety, accessibility, and a durable design. Guided by these results, we designed a proof of concept (POC) system called the Affordable Smart Wheelchair (ASW) for indoor use. This kit implements full-autonomy in the form of indoor navigation from one room to another and to predetermined docking locations through voice control. It also has semi-autonomous functions in the form of manual joystick control augmented with real-time collision avoidance and staircase detection.

CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)**; **Participatory design**; *Interaction design*; *Accessibility*; User studies; User centered design;

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BACKGROUND AND MOTIVATION

Wheelchairs enable people with mobility challenges to experience higher quality lives, they allow users to rely less on caregivers for mobility. In 2018 it was estimated that 70-100 million people were in need of a wheelchair, yet only 10% of these needs were met [12] [1]. A relatively recent improvement upon the manual wheelchair is the PW. These are often used by individuals who are unable to use a manual wheelchair. However, current PWs are not adequate for many individuals because they are not affordable and are difficult to use, often lacking motor skills [11] necessary to use them. An average PW in Asia and in the US costs about $1,600 and $7,000 respectively [4] yet many individuals in Asia who need wheelchairs are below the poverty line [8] with incomes as low as 12 USD per month [10], making PW inaccessible to a large portion of the global population.

To address design inadequacies, a PW can be modified to include levels of autonomous capabilities, such as collision avoidance or path planning. These are smart wheelchairs (SW) and exist in the form of commercial or research projects [9]. Commercial SWs are less accessible financially than PWs, their high retail price ranging between $9,500 and 25,000$ [14]. Moreover, SW projects are developed in specialty engineering research labs requiring a challenging skill set and prohibitive cost to reproduce

Wheelchair Factors Learned
- Waterproof
- Struggle with side transfer to and from wheelchair
- Recognizing only the users'voice
- Voice control usable in noisy environments
- Struggle with non-adjustable wheelchair heights

Figure 3: List of factors that users interviewed related to us with their continuous interaction

Questions Asked
- What type of wheelchair do you use?
- What customization have you made to your home and wheelchair?
- What is your health condition?
- Describe your Day-in-a-Life

Figure 4: List of most relevant questions that were asked to users

easily. Our student research and development team seeks to design a system that is accessible and affordable to users across the globe with a focus on human-centered design.

RELATED WORK

Past research explored ways of interacting with a wheelchair [13] [9] [15]. However, these efforts have been technology-centered instead of human-centered. For instance, Carlson explored in [9] the application of a Brain Computer Interface for controlling the wheelchair. Yet, the technology-centered approach did not consider the learning curve associated with the interface, leaving inexperienced users unable to use the wheelchair effectively. Other relevant efforts such as [16] and [11] show the lack of satisfaction with existing manual wheelchairs and PWs among users. In [16], Samuelsson and Wressle explore the levels and reasons for the satisfaction of individuals with their manual wheelchairs and rolling walkers. They found that across all factors considered, wheelchair users were less satisfied than their rolling walker user counterparts; these factors included -but were not limited to- safety, durability, and ease of use [16]. In a survey of 200 practicing clinicians Fehr, Langbein and Skaar [11] found that about 40% of the patients had trouble with the steering and maneuvering of their PWs, To address these issues we include room-to-room navigation and collision avoidance in our system.

RESEARCH APPROACH

Our approach to design as a team was to follow the DD method, which divides the design process in 4 recognizable phases: Discover, Define, Develop, and Deliver [2]. To achieve a human-centered design, we followed the guidelines for PD throughout the design process, which emphasizes the recurrent engagement with stakeholders [7]. PD allows us to gain insight from stakeholders that we would not have otherwise. Through recurrent lab visits by multiple wheelchair users and researchers, we learned of the following important factors as seen in Figure 3.

Approach for Obtaining User Input

All of the users interviewed were initially contacted through organizations or university departments which agreed to participate in our study. Before the domestic user interviews were conducted, individuals agreed to fill out a questionnaire survey of 11 questions. The questions asked were open ended to ensure unrestricted responses and to create character profiles of users. A short compilation of the most relevant questions can be seen in Figure 4. Once these surveys were completed, we maintained contact with those who agreed to personal interviews and requested feedback to continue interaction with our team throughout the design process. Furthermore, we carried out interviews of healthcare professionals that work with wheelchair users to obtain a unique perspective of challenges such as strategic placement of ramps. The questions asked to these professionals were aimed at relating the different ways in which accommodations are made for disabled individuals and why they are needed.

Wheelchairs Used			
Location	Manual	Power	None
International	16	3	0
National	16	17	4

Figure 5: The different types of wheelchairs and the locations of the users that were contacted

Wheelchair Use Cause		
Cognitive Disability	Physical Disability	Injury
Number of Individuals		
16	17	12

Figure 6: Distribution of reasons users used wheelchairs

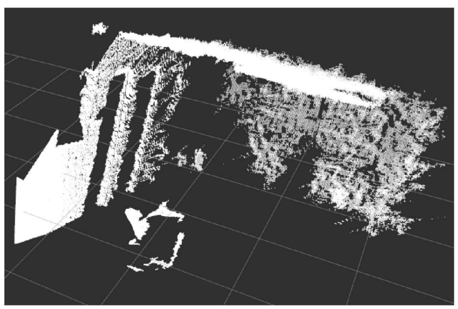

Figure 7: Point cloud map of a section of our lab

RESULTS

We obtained responses from nearly 70 individuals through both our survey and interview processes across 7 countries including: India, Sri Lanka, Egypt, United Arab Emirates, Mexico, the United Kingdom, and the United States. From those 70 individuals, 30 interviews were conducted, more than half of which were international.

The distribution of wheelchairs used by the users interviewed can be seen in Figure 5, and the distribution of the types of disabilities in users can be seen in Figure 6. The rest of those who were surveyed or interviewed were either professionals or not bound to a wheelchair. Some users complained about a constant fear of colliding with objects in their house. Many users resorted to or desired adjusting their homes to accommodate their movements. Those interviewed with cognitive challenges, especially those with Myalgic Encephalomyelitis (ME), reported having "good days," where they can perform habitual tasks, and "bad days," where even standing up is a struggle.

DISCUSSION

Several themes emerged in our research through the analysis of the surveys and the interviews conducted. These became important design guidelines.

Accessibility

As seen in Figure 5, among international users, 16% used PWs and 84% used MWs, compared to 51% of PW users and 49% of MW users in the US. This imbalance in MW and PW users along with the high retail cost of PWs as seen in [4] suggests that PWs are less accessible internationally than in the US.

Bimodal Autonomy

Due to the variance in cognitive functionality, people with ME can benefit from a bimodal autonomy system. On a "good day," it is possible to control the joystick as desired, but on a "bad day" they can rely on a smart wheelchair to navigate them safely through their home. Hence the design of a bimodal autonomous system is necessary. On the other hand, people who suffer from degenerative physical disabilities, such as Spinal Muscular Atrophy, cannot use a fully-autonomous wheelchair because inactivity leads to further bodily deterioration.

Durability and Maintenance

The design should be easily repairable. To speak to this, we share the story of a young man who was left out of any control of his wheelchair when his tongue controller broke. It took three years until someone was able to fix his technology.

Figure 8: Indoor environment map of our lab done through ROS

Sensors
- Stereo Camera: real time depth map
- 2D LiDAR: indoor environment map
- Inertial Measurement Unit (IMU): tracking relative angular position of the wheelchair
- Time of Flight (ToF): distance to obstacles
- Encoders: physical distance travelled

Figure 9: List of sensors used in our proof of concept

Safety

The wheelchair users interviewed described the greatest mobility challenges in their everyday lives to include obstacles such as stairs, curbs, side transferring, and narrow passages. This demonstrates the need for features, such as obstacle and drop-off detection and obstacle detection, intended to protect the user from harm and their property from being damaged.

PROOF OF CONCEPT

After conducting the interviews and establishing the requirements that a smart wheelchair needs to address, we developed a POC wheelchair. It uses the robust Robotic Operating System (ROS) for navigation. The sensors used in the system and the role played by them is displayed in Figure 9. The fully autonomous functions of the POC wheelchair include room-to-room and predetermined docking location navigation. The voice control interface with the listed sensors allows us to perform the above mentioned autonomous functions through affordable components. As for the partial autonomy while controlling through the manual joysticks, the POC wheelchair uses an onboard Time of Flight sensors which assist the users through functions such as avoiding nearby obstacles, staircase detection and collision avoidance.

LIMITATIONS AND FUTURE WORK

Our project is limited to indoor use due to challenges in outdoor environments, such as not efficient sensors or rough terrain. A limitation in the user research conducted is the imbalance in the geographic distribution of the users contacted. Out of 52 wheelchair users contacted, 33 were from the US alone. A practical limitation of the POC wheelchair designed is that the 3D printed sensor mounts are specific to the KD Smart Chair because of practical financial limitations. KD Smart Chair donated one wheelchair and heavily discounted a second wheelchair to our group to develop the POC.

As discussed earlier, we developed a POC wheelchair kit to test the insights that emerged from interact- ing with wheelchair users. Future extensions of the work would include validating the kit developed by conducting user studies with our POC. We plan to address the limitations of our work to include a universal sensor mount for the ASW kit and expand to an outdoor environment. In addition, future efforts need to take into consideration affordability to individuals across the global community and the technical expertise required to reproduce the system outside of research laboratories.

RESEARCH NOVELTY AND CONTRIBUTIONS

This engineering research project is unique in that it takes on a human-centered approach through the entire development process. Instead of a technology-centered approach that excludes the richness of user experience, we used PD to drive our design priorities. To address the needs of individuals, it is necessary to consider their insights as well as those of others in the community that engage with wheelchair users regularly. Not only are wheelchairs essential to mobility for users, but they can also be considered an extension of the self. Current technology, in many ways, is geared to an average user, while this project aims to appeal to the DIY, personalized tailoring of technology kits. We hope to address the large disparity of MWs and PWs in the international community, due to pricing. Our POC aims to solve this by being an open source project that anyone could use.

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REFERENCES

[1] [n. d.]. ABOUT. https://wheelchairfoundation.org/about/
[2] [n. d.]. The Design Process: What is the Double Diamond? https://www.designcouncil.org.uk/news-opinion/design-process-what-double-diamond
[3] [n. d.]. EV Rider Vision P13 Power Wheelchair. https://wheelchairnetwork.com/products/ev-rider-vision-p13-power-wheelchair?variant=12533599240258&gclid=EAIaIQobChMIqM7huZ3b3wIVgiJpCh3bkQE3EAQYASABEgLhxPD_BwE
[4] [n. d.]. How Much Does a Wheelchair Cost? - CostHelper.com. https://health.costhelper.com/wheelchair.html
[5] [n. d.]. Literider Envy. https://libertymedic.com/products/literider-envy?variant=12442329120829&gclid=EAIaIQobChMIu_Hvl53b3wIVCYZpCh3NOw3rEAYYAiABEgI-UPD_BwE
[6] [n. d.]. What is AT? https://www.atia.org/at-resources/what-is-at/
[7] [n. d.]. What is Participatory Design? http://participateindesign.org/approach/what/
[8] 2018. World report on disability. https://www.who.int/disabilities/world_report/2011/en/
[9] T. Carlson and J. del R. Millan. 2013. Brain-Controlled Wheelchairs: A Robotic Architecture. *IEEE Robotics Automation Magazine* 20, 1 (March 2013), 65–73. https://doi.org/10.1109/MRA.2012.2229936
[10] Planning Commission. 2011. *Report of the Expert Group to Review the Methodology for Estimation of Poverty*. Working Papers id:4531. eSocialSciences. https://ideas.repec.org/p/ess/wpaper/id4531.html
[11] L Fehr, W E Langbein, and Steven Skaar. 1999. Adequacy of power wheelchair control interfaces for persons with severe disabilities: A clinical survey. *Journal of rehabilitation research and development* 37 (11 1999), 353–60.
[12] Director General. [n. d.]. Improving access to assistive technology. http://apps.who.int/gb/ebwha/pdf_files/EB142/B142_21-en.pdf
[13] Martin Gerdzhev, Joelle Pineau, Ian Mitchell, Pooja Viswanathan, and Genevieve Foley. 2016. On the Use of Modular Software and Hardware for Designing Wheelchair Robots. https://www.aaai.org/ocs/index.php/SSS/SSS16/paper/view/12704/11930
[14] Tam Harbert. 2015. Will the Whill Hi-Tech Wheelchair Sell? https://spectrum.ieee.org/biomedical/bionics/will-the-whill-hitech-wheelchair-sell
[15] Y. Matsumotot, T. Ino, and T. Ogsawara. 2001. Development of intelligent wheelchair system with face and gaze based interface. In *Proceedings 10th IEEE International Workshop on Robot and Human Interactive Communication. ROMAN 2001 (Cat. No.01TH8591)*. 262–267. https://doi.org/10.1109/ROMAN.2001.981912
[16] Kersti Samuelsson and Ewa Wressle. 2008. User satisfaction with mobility assistive devices: An important element in the rehabilitation process. *Disability and Rehabilitation* 30, 7 (2008), 551–558. https://doi.org/10.1080/09638280701355777 arXiv:https://doi.org/10.1080/09638280701355777 PMID: 17852301.