Integrating Urban Accessibility into Human-Robot Interaction Evaluation

Howard Han Carnegie Mellon University, Pittsburgh, PA, USA, `ziyuh@cmu.edu`

Howard Han is a PhD student in Human-Computer Interaction Institute at Carnegie Mellon University advised by Nik Martelaro. His research focuses on building participatory tools to deliberate public AI technology so that it does not disproportionately affect marginalized communities and complicate their daily tasks. He holds a bachelor's degree in Urban Planning and a master's in Computational Design from CMU.

Sarah Fox Carnegie Mellon University, Pittsburgh, PA, USA, `sarahfox@cmu.edu`

Sarah Fox is an Assistant Professor in the Human-Computer Interaction Institute at Carnegie Mellon University, where she directs the Tech Solidarity Lab. Her research examines how technological artifacts challenge or propagate social exclusions. She holds a Ph.D. in Human Centered Design & Engineering from the University of Washington.

Nik Martelaro Carnegie Mellon University, Pittsburgh, PA, USA, `nikm@cmu.edu`

Nik is an Assistant Professor at Carnegie Mellon's Human-Computer Interaction Institute. His lab focuses on augmenting designers' capabilities through the use of new technologies and design methods. His interest in developing new ways to support designers stems from his passion for creating interactive and intelligent products. He combines a background in product design methods, interaction design, human-robot interaction, and mechatronic engineering to build tools and methods that enable designers to better understand people and create more human-centered products. Before joining the HCII, Nik was a Digital Experiences researcher at Accenture Technology Labs in San Francisco. He earned his Ph.D. in Mechanical Engineering from Stanford's Center for Design Research.

Motivation

Our group has been conducting research to understand the navigation challenges faced by people with mobility disabilities when sharing sidewalks with delivery robots. This work has involved exploring various Human-Robot Interaction (HRI) design factors, understanding roboticists' perspectives on improving sidewalk accessibility, and co-designing public service robots that prioritize the needs of people with mobility disabilities.

We are currently focused on enhancing existing HRI social navigation evaluation tools by incorporating insights and challenges on urban accessibility identified in our previous research. By engaging with the urban accessibility community, we aim to refine our designs to better align with the practical needs of people with disabilities and discuss accessible public service robots.

1 Introduction

As robots transition from industrial and private domains into public spaces, they hold the potential to become components of urban life [8, 9]. While these robots cater to specific stakeholders, they may inadvertently disrupt the navigation of other user groups who neither utilize nor anticipate their presence [1]. Research has highlighted the challenges that people with disabilities (PWD) face when navigating around these robots, indicating that roboticists have yet to create accessible robot technologies [6]. Our prior co-design study demonstrated that collaboration between robotic engineers and PwMD can effectively address minor accessibility issues and generate new interaction methods that enhance interaction and environmental accessibility [7]. Despite these promising outcomes, such co-design workshops often struggle to bridge the gap between initial ideas and practical implementation.

Designing accessible public robots involves more than just stakeholder participation; it requires a holistic integration throughout the entire development process, from initial idea generation through to implementation and evaluation. The Human-Robot Interaction (HRI) community has called for more consideration of fairness and inclusivity, emphasizing the need to involve impacted stakeholders who have yet to have a say in robot technologies. To ensure urban sidewalks are accessible to all, roboticists can benefit from incorporating the requirements and feedback of people with mobility disabilities (PwMD) directly into their algorithm development processes. Although advancements have been made in HRI regarding social navigation tools—some of which utilize real-world video data to analyze pedestrian patterns—these tools do not address the specific tensions experienced by PwMD and individuals with limited mobility [2, 11]. They often fail to adequately represent PwMD and other sidewalk users whose navigation becomes more complex due to robots. Interviews with roboticists also reveal a potential lack of awareness and thorough evaluation of the intricacies of public spaces.

To address these challenges, we propose integrating urban accessibility considerations into HRI tools used for developing and evaluating autonomous agents operating in public spaces, such as service robots and autonomous wheelchairs [4, 10]. Insights from urban accessibility communities provided abstractions of the complex dynamics of sidewalk environments, highlighting the navigation challenges faced by people with disabilities and the impact of new mobility technologies [5, 12]. These insights should be translated into guidelines for training robot policies that function effectively on sidewalks. Consequently, robot policies informed by the intricacies of urban accessibility can enhance public acceptance and facilitate smoother integration into everyday environments, complete with robust exception handling. Recent progress in robot learning has facilitated more agile robot behaviors in real-world settings, enabling them to perform services in complex settings and respond to spontaneous instructions. To harness these technology capacities, the involvement of PwMD can create public robots that are not only intelligent but also inclusive and accessible. In the co-design workshops we conducted, people with disabilities collaborated with roboticists to develop robots for tasks such as snow clearing, safeguarding crosswalks, and cargo transportation. Collective ideations of these robotic technologies can pave the way for robots that genuinely enhance urban accessibility (Refer to fig.1).

2 Design Goals for Enhancing Accessibility in HRI Tools

Building upon the findings from urban access and the HRI community, we synthesized design goals (DG) of development tools for public service robots (Refer to table 1). These goals focus on embedding accessibility considerations into the prototyping and evaluation phases, enabling developers to detect and resolve potential accessibility issues early in the design process.

To explore the practical application of these design goals, we conducted a preliminary study using a simulation tool based on Wizard-of-Oz (WoZ) methods. This tool was designed to simulate realistic interactions between robots and PwMD within a virtual environment that incorporates the proposed design goals.

The simulation took place in a high-fidelity virtual model from the Unity Asset Store [1]. It was based on the New York City residential area, incorporating typical sidewalk features such as curb cuts, street furniture, and varying pavement conditions. The sidewalk model contained fire hydrants, trash cans, and fallen leaves, roughly representing the sidewalk condition of Pittsburgh, where we conducted the study (Design Goal 5). To simulate the real-world experiences of people with disabilities, we implemented a wheelchair user model (Design Goal 1). The virtual robot agent was controlled by one operator using a joystick, while another operator controlled the wheelchair user agent. Each scenario required the

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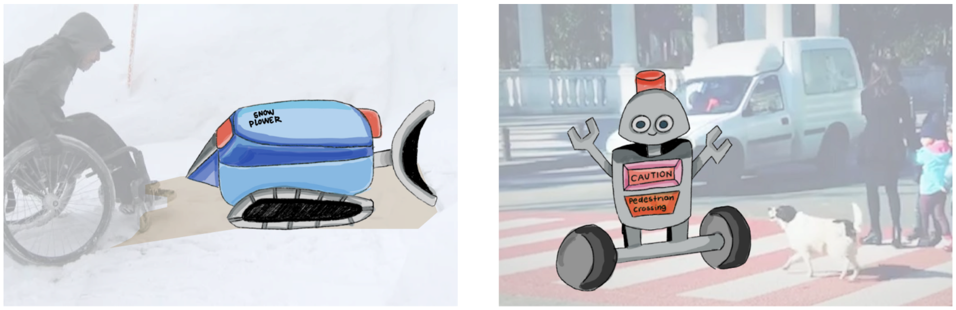
[1] Resource: https://assetstore.unity.com/packages/3d/environments/urban/street-new-york-183319

(a) Cargo Carrier Robot designed in Workshop 1

(b) Grocery Fetcher Robot designed in Workshop 2



(c) Snow Plow Robot designed in Workshop 3

(d) Crosswalk Guider Robot designed in Workshop 4

Fig. 1. Final illustrations of the robot ideas from the four co-design workshops. The illustrations have also been photo-edited to depict the public venue they operate within in the background.

two operators to work in sync, managing both agents and tracking their movements. In the human perspective view, the first-person camera was set to the wheelchair user's eye level. Additionally, the prototype included a VR mode, allowing participants to navigate using VR joysticks.

We evaluated the benefits of realizing the design goals through two preliminary explorations: interviews and VR demonstrations. In the first experiment, we conducted interviews with two participants who were wheelchair users. We used two videos built from our tool as interview prompts:

(1) One scenario video depicted two social navigation strategies, where the robot and a male wheelchair user walking on foot approached each other from opposite ends of a sidewalk. In this video, the robot bypassed the person with disability agent by turning and maintaining a safe distance, while in another video, the robot stopped 2 meters away from the human agent, allowing them to pass first.
(2) Another scenario video depicted speed testing, where the male wheelchair user was stationary, and the robot moved at different speeds between 3.4 mph and 10 mph, bypassing the wheelchair user at a safe distance.

The second experiment user engagements involved a VR experience in which we replicated a real-world accident where a robot blocked the path of a wheelchair user by stopping on the curb cut (DG2). To carry out this experiment, we recruited two able-bodied participants (P3-4) as pilot testers, who were trained to use joysticks to move forward in the VR environment. Participants were instructed to cross a crosswalk from the opposite side of the road and observe a delivery robot moving forward and stopping at the curb cut. Upon arriving at the other side, the delivery robot remained stationary. We encouraged participants to express their thoughts during the interaction.

Design Goals	**Motivation**	**Implementation**
1. Heterogeneous pedestrian representations and navigation model	Navigating public sidewalks can be particularly challenging for individuals with mobility impairments, especially when sidewalk conditions are suboptimal. Current HRI simulation tools often oversimplify these complexities by representing pedestrians as homogeneous agents, typically able-bodied individuals walking on foot.	Development tools should enable the simulation of a diverse range of sidewalk users, including wheelchair users, individuals with assistive devices, and people with varying mobility levels.
2. Simulation of Potential Navigation Conflicts	To ensure that pedestrians maintain agency in public spaces and are not silently marginalized by robotic systems, it is crucial to identify and address potential conflict points in robot-pedestrian interactions. This includes scenarios where robots may obstruct access or create hazards for PWD.	Simulation environments should involve challenging scenarios such as navigating around curb cuts, dealing with broken or uneven sidewalks, and managing sidewalk blind spots. By testing robot behaviors in these conflict situations, developers can refine algorithms to prevent obstructions and enhance safety.
3. Supporting Multimodal Interaction for People with Disabilities	People with disabilities (PWD) often encounter difficulties when robots rely only on traditional input methods like touchscreens, small buttons, or physical controls. For instance, individuals with limited hand mobility may find touch-based interfaces challenging, while others with visual impairments might struggle with non-auditory controls.	Development tools should support the testing and evaluation of various interaction modes, including voice commands, gesture recognition, and accessible touch interfaces. Additionally, these tools should assess how effectively robots can adapt between these methods based on the user's needs and environmental context.
4. Implementation of Clear Signaling and Communication	Effective communication of a robot's intentions is essential to prevent confusion and enhance user trust, particularly for PwMD who may require additional cues to interpret robot behaviors.	Tools should allow developers to test different signaling methods, such as auditory alerts, visual indicators, and haptic feedback, in various scenarios. Evaluating the effectiveness of these signals can help in designing robots that communicate clearly and appropriately with all users.
5. Incorporation of Local Community Contexts and Members	Sidewalk conditions and community demographics can vary significantly across different regions, affecting how robots are perceived and how they should behave.	Simulation environments should reflect the specific sidewalk conditions and cultural contexts of local communities. Engaging local community members in testing can provide valuable insights and ensure that robots are tailored to the needs and expectations of the populations they serve.

Table 1. Design Goals, Motivation, and Implementation

3 Implications on Public Space Human-Robot Interaction

Prior robot evaluations often center around technical precision and optimal pathfinding, leaving out key experiential factors, particularly those impacting people with disabilities [3]. Our incorporation of urban accessibility into this tool showed that when HRI researchers engage with PwMD directly in robot algorithm evaluations, previously unseen

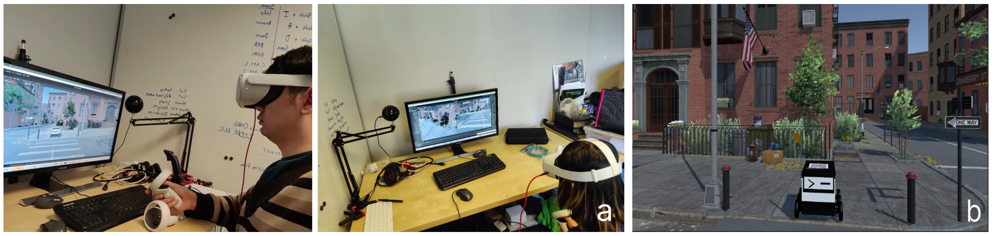


Fig. 2. (a) Participants wear headsets and use joysticks to move in VR. (b) The view of VR when participants arrive on the other side

challenges emerge. P2, a manual wheelchair user, when seeing the navigation videos, noticed that there were outside tables and commented, "I hope it (the robot) won't get stuck when passing the chairs…and block my way" highlighting potential mental stress spotting robots during navigation. The first-person participation also enabled them to notice details on sharing the sidewalk that might be hard to find by other methods. For instance, during the VR experience, P3 noticed that the robot's stop position prevented him from passing the road corner due to his wheelchair needing a large turning radius. This dynamic interaction introduced unexpected conflicts even though the robots respected the proxemics. Another example is that, in response to the fast-moving robot video, P1, a wheelchair user, commented that she would fail to adjust in time when robots ran fast because of her lack of proficiency in maneuvering the wheelchair. This navigation pattern and challenges might have been overlooked if we only used walking people models.

The findings also showed limitations of current metrics used to evaluate robot social navigation, particularly those that focus solely on proxemics—the physical distance maintained between robots and humans. Although these metrics measure "smooth navigation," our participants' experiences reveal that PwMD may still face significant challenges, even when the robot meets these criteria. Our preliminary study suggests that smooth navigation, typically designed around able-bodied pedestrians, needs a more detailed and user-centered approach. Future simulation tools should adopt new metrics, such as "accessible navigation," which take into account the diverse needs and behaviors of PwMD in real-world settings.

Another finding relates to the communication and interaction needs of PwMD when sharing sidewalks with robots. For instance, during the social navigation video, P2 requested to pause at the moment when the robot stopped too close, stating, "I probably cannot accept the robot being that close to me… I want to yell at it to back off." Similarly, P3, during the VR test, expressed frustration when approaching a robot, saying, "I really want to yell for the robot to go away." These moments demonstrate the importance of enabling more responsive and multimodal interactions between robots and users. Evaluation tools should be designed to capture these specific interaction contexts and support testing of multimodal communication methods, such as voice commands or gestures, that would allow users to convey their needs effectively.

Currently, most social navigation evaluations focus on robot navigation policies, neglecting the interaction capabilities that are crucial for PWD. Our findings suggest that blending navigation policies with interactive communication channels is essential, as there will be situations where adjusting proxemics alone is not sufficient. PwMD may have needs that cannot be addressed simply by the robot adjusting its distance. Without proper channels for users to communicate directly with robots, silent navigation can lead to negative experiences, potentially diminishing the sense of agency PwMD have in public spaces. Therefore, incorporating interactive, user-centered communication into robot designs is critical for ensuring more equitable and accessible urban environments.

4 Conclusion

Although still in the early stages, our experiments with people with disabilities have revealed some of the assumptions that roboticists have made about their ability to interact with robots and evaluation criterion that may be wrong. Our group is working on integrating other design goals into existing robotic evaluation infrastructures to align more with current Human-robot interaction researchers and developers' workflow and get feedback on how they would use them to introduce the notion of urban accessibility to the public service robots community. Ultimately, we envision a co-creation process where diverse users, including people with disabilities, directly influence how public robots operate, ensuring that these technologies genuinely enhance the accessibility of shared urban spaces.

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