

The Robot in Our Path: Investigating the Perceptions of People with Motor Disabilities on Navigating Public Space Alongside Sidewalk Robots

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ABSTRACT

Sidewalk robots are becoming increasingly common worldwide, yet their operation on public walkways presents challenges for pedestrians. This is especially true for people with motor disabilities (PWMD) who already manage obstacles such as inadequate ramps and public incivility. The addition of sidewalk robots could further intensify these difficulties, which poses an urgent need to examine how the design of sidewalk robots may influence the daily navigation experiences of PWMD. This poster illustrates findings from semi-structured interviews with ten PWMD, providing insights into their perspectives on the presence of sidewalk robots. The study uncovers potential conflicts in shared sidewalk use and the adaptive actions PWMD described needing to undertake in response. Interviewees raised concerns about whether the robots could accommodate the needs of PWMD, as compared to people walking on foot, and the repercussions of any shortcomings in this regard. Our research also examines tensions stemming from different robotic design choices, indicating the necessity for more accessible public robot designs. We further delve into PWMD's interaction needs and modalities for routine operation and in the event of robot malfunction. As cities increasingly allow for the deployment of robots in public spaces, this work seeks to inform equitable design and deployment guidelines for sidewalk robots and calls for further research into the implications of the rise of public robots for the diverse populations that make up any given municipality.

CCS CONCEPTS

• **Human-centered computing** → **Accessibility**; • **Computer systems organization** → **Robotics**.

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KEYWORDS

sidewalk robots, delivery robots, public space, human-robot interaction

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1 INTRODUCTION

Alongside the widening use of service robots generally, sidewalk robots are among the newest innovations to be introduced into public spaces [4, 22, 27]. In 2021, the International Federation of Robotics projected a 40% annual growth in the use of mobile robots in public environments¹. Several companies such as FedEx, Starship, and Uber Eats are currently testing or deploying delivery robots designed to deliver food, medicine, and other small cargo [2]. However, when sidewalk robots navigate pedestrian walkways, most people they interact with will, in fact, not be users, but instead just “happen to be there” [22]. Among those passersby will be people with mobility disabilities (PWMD)—such as wheelchair users—whose needs should be centered in any debate or development of such devices [4]. Despite this, some states have proactively embraced this technology; Pennsylvania, for instance, recently defined delivery robots as “pedestrian” under state law, ostensibly giving them the same legal rights as human residents [1].

Conversely, ongoing studies have revealed potential conflicts between PWMD and sidewalk robots [3–5, 27]. Drawing on interviews with multiple stakeholders containing disability advocates, Bennett et al. found that micro-mobility deployments may re-introduce access barriers long fought against by the disability rights community [18]. Additionally, the paper's second author, a wheelchair user, experienced a dangerous encounter with a sidewalk robot.

¹Data Resource: <https://ifr.org/ifr-press-releases/news/mobile-robots-revolutionize-industry>

The device stopped on the curb cut, blocking a safe path for her to cross and clear to the other side of the road. After sharing a Tweet recounting the experience [3], the company removed the robot for a brief time. However, she received backlash for “*whining*”, given that she “*was not hit by a car*”. This incident—and the subsequent responses—highlights a clear knowledge gap around PWMD’s interactions with sidewalk robot and the need to maintain accessible public walkways.

This paper aims to elucidate the complex relationship between sidewalk robots and PWMD and inform the design and operation of these robots in a safe and socially acceptable way. To this end, we pose the research questions:

- How do PWMD perceive the presence of sidewalk robots? How do they imagine encountering and interacting with these devices as they are currently deployed?
- Do differences in robot design or communication techniques change the way sidewalk robots are perceived?

2 METHODOLOGY

To understand how PWMD perceive sidewalk robots and investigate potential interaction methods, we interviewed 10 PWMD (7 female, 3 male). Participants’ average age was 31 years of age ($SD=10.0$) and they were recruited through online platforms like Reddit and Twitter. All interviewees had a motor disability with two participants having interacted with sidewalk robots before (See supplementary material for a full demographic table). Interviews lasted 60–80 minutes, and participants were compensated with a \$20 Amazon gift card. Our university’s Institutional Review Board (IRB) approved the recruitment and study procedure.

2.1 Interview procedure

We first asked our participants for their demographic information, such as age, gender, and specifics of their mobility impairments. To ensure participants were familiar with the concept of sidewalk robots, we showed a video of a functioning delivery robot and images of various sidewalk robots [17]. As a starting point to discuss different design forms, we also presented eight widely recognized design factors from the Human-robot Interaction (HRI) literature to each participant (See Fig.1 for descriptions [6, 8, 10, 11, 13–15, 19–21, 24–26, 28]). For example, we illustrated different social navigation strategies sidewalk robots might exhibit, one of which is that robots could halt their movement to allow the PWMD to pass in an attempt to prevent collisions or maintain distance. By presenting an array of existing design solutions and factors, we aimed to offer a comprehensive overview of current robot forms and behaviors, thereby encouraging participants to articulate their perceptions in relation to existing designs. Subsequently, we invited our participants to discuss how these factors might influence their perceptions and navigation experiences. We then delved into their preferred modalities for each interaction. This section of the interview sought to uncover the participants’ needs in relation to potential interactions with the robots, and issues of usability that could emerge with different interaction modalities.

2.2 Data analysis

Two research team members coded two transcripts using bottom-up coding strategies to build a codebook [10]. The first author independently coded all remaining data, with all authors convening to discuss and resolve conflicts (e.g., missing code, disagreement on codes). Each code, along with its corresponding interview transcript section, was sorted into an affinity diagram. This process continued until broader patterns and relationships appeared.

3 FINDINGS

In this section, we present three themes of PWMD perceptions of sidewalk robots (Section 3.1.1 - 3.1.3), and two themes related to the interaction, including the purpose (Section 3.2.1) and usability of interaction modalities (Section 3.2.2).

3.1 Perception of Sidewalk Robots

3.1.1 Sidewalk Resources and Robotic Behaviors. A unanimous concern among participants was the **potential scarcity of sidewalk space** if the robots failed to adjust their routes as necessary. For PWMD, this issue significantly complicates the process of maneuvering around the robots, potentially forcing them to **resort to dangerous or inconvenient path adjustments**. P1, for instance, expressed concerns about getting trapped on the sidewalk when encountering these robots: “...*especially if there are also trees and bricks that might obstruct me. Do I have any space to move around? Most likely, I would have to go down the sidewalk! But after I get down, can I come up again, or is there any way to make [the robot] move away?*” A similar concern was echoed by six other participants, who suggested various **coping strategies**, such as backing up, leaving the sidewalk to allow the robots to pass (P1, P6, P9), venturing onto potentially hazardous grassy or uneven areas (P4, P9), seeking shelter by residences or stores (P8), or modifying their original route (P10). However, some of these actions could pose challenges due to motor impairments.

Curb cuts emerged as another critical resource PWMD perceived as being a site of potential conflicts with sidewalk robots, suggesting that real-world accidents might not be isolated incidents. All participants acknowledged the irreplaceable value of curb cuts and voiced concerns about how robots’ presence might exacerbate their existing scarcity. P4 explicitly shared their worry that “...**the curb cuts could be a point of contention** when I need the curb cut and the robot also needs the curb cut when we’re trying to get on.” This apprehension around the loss of access to curb cuts was amplified when interviewees considered the scenario of multiple robots operating on sidewalks concurrently. When presented with an image of several robots on a sidewalk, an overwhelming majority of participants (9 out of 10) reacted negatively. P2 mentioned: “...*If I come across a line of small robots near the curb cut, I might choose to stop, even if I have pressing matters to attend to, I would wait for them to pass first...*” P1 and P9 shared similar **anxieties about navigating past a group of robots**. Despite there being space between the robots in the image, interviewees expressed hesitation, attributing this to the challenge of judging the adequacy of the space and the unpredictability of the robots’ movements.

Factor name	Description	Citation	Factor name	Description	Citation
1  Robot size	We offered participants a comparison of two sidewalk robots of distinct dimensions. The larger robot's specifications were based on FedEx Roxo, (147.3 cm x 71.1 cm x 91.4 cm), while Starship's robot represented the smaller one (55.4 cm, 56.9 cm, 67.8 cm).	[15]	2  Robot group	We provided images of sidewalk robots exhibiting different color contrasts, inquiring how color variation might affect participants' perceptions of the robots.	[11]
3  Approaching strategy	Approach strategy pertains to the robot's navigation methodology to approach a target. We presented participants with two videos, each depicting different approach strategies and turning points, aiming to elicit their responses to diverse navigating behaviors.	[19,13,28]	4  Social navigation	Participants were shown two social navigation strategies a robot might employ when encountering a pedestrian - maintaining a safe distance while navigating around the pedestrian, or halting movement entirely to allow the pedestrian to pass.	[20,24,14]
5  Communicative signals	Participants were presented with five communicative signals currently used by sidewalk robots - sound, facial expressions, on-screen text, on-screen icons, and lights. They were asked to share their perceptions and potential use cases for each.	[8,6]	6  Speed	Three speed levels were presented: Fast (10 mph), Normal (3.4 mph), and Slow (2 mph). Participants were asked to share their perceptions and potential responses to encountering robots at these different speeds.	[25]
7  Color	We provided images of sidewalk robots exhibiting different color contrasts, inquiring how color variation might affect participants' perceptions of the robots.	[21]	8  Proxemics	Images depicting robots at varying distances from pedestrians were provided, and participants were asked to discuss how these distance variations might alter their perceptions of the robots.	[25, 26, 14]

Figure 1: Drawing from existing literature, we identified eight critical HRI design factors. This figure provides an overview of these factors, elucidates how they were presented to the participants, and references the corresponding literature.

Given that the sidewalk robot was a relatively novel concept for most of our participants (and the public more generally), interviewees noted that **sudden changes in their behaviors would lead to confusion**. For instance, P8 exhibited bafflement when a robot paused to give way in one of the videos depicting its behaviors, leading to speculation about potential malfunctions and concern that *“the robot stops for a specific reason.”* This resulted in a reluctance to proceed, driven by fear and uncertainty. P2 expressed a similar sentiment, suggesting, *“I would probably let them pass first because I am somewhat fearful.”* Such uncertainties, compounded by a reluctance to approach the robots out of causing damage, could pose significant navigation challenges for PWMD when encountering these machines in public.

3.1.2 Recognition and adaptation to PWMD. PWMD often relies on mobility aids like manual wheelchairs, and canes which may pose challenges to the adaptive behavior of robots. Six participants expressed concern about whether the robots would be **capable of effectively navigating around them**. However, in contemplating whether the robots could halt their movement to allow the PWMD to pass, P1 and P3 highlighted a key concern that the robots' stopping points often landed in the trajectory of their wheelchairs. As a result, to avoid the stationary robot, they would have to adjust their own paths. This adjustment is not a straightforward task; for PWMD, especially those relying on manual wheelchairs, altering the direction involves physical effort and precise maneuvering, which can be time-consuming.

As a remedy, three participants voiced they will be more reassured if **the robots show that they can recognize their disabilities**. P8 expressed a desire for robots to exhibit some form of acknowledgment when detecting a wheelchair and have behavioral changes, like being slower. P4, agreeing with this idea, underlined the importance of recognition as a fundamental functionality for robots to learn how to *“treat PWMD respectfully.”* They also suggested a user interface similar to those used in autonomous vehicles, where pedestrians' movements and relative positions are displayed, so they can be more aware of the robots' intentions and planned actions. However, our participants also raised concerns about the

robot's proficiency in accurately recognizing and responding to the diverse range of mobility aids and their distinct usage patterns, which could be challenging even for the users themselves to articulate.

3.1.3 HRI design factor tensions. Participants' divergent needs highlight the **complexities of designing robots for public spaces**, where dynamic scenarios are the norm. For example, in terms of the form of robots, large robots were more likely to obstruct sidewalks and invoke fear (P2). Smaller robots elicited less fear and took up less sidewalk space, but they presented a different issue of potentially trapping pedestrians. P8 observed that *“(Wheelchair users) may not see the smaller robot if not spotted from a distance.”* They appreciated the inclusion of a flag as a visibility feature, especially for low-to-ground robots, but expressed concern about its snagging on wheelchair attachments.

Robot form also affected **signal visibility and interaction accessibility**. Three participants expressed concern that information displayed on the robot, such as text or images, might be challenging to see. P1 expressed concerns about the difficulty of interacting with shorter robots: *“I feel that the (small robot) is less user-friendly because I can at least touch the top of the taller one. I envision that the taller one might have operational or interactive functions on top, so I can effectively communicate to it...”*

3.2 PWMD's Interaction with Sidewalk Robots

3.2.1 Purpose of the interaction with Sidewalk Robots. Considering the potential conflicts and concerns presented above, all participants underscored the importance of **interacting with sidewalk robots to ensure safety**. Critical situations like competing for curb-cut access or **evading dangerous areas necessitate effective communication with the robots**. Voice interaction was considered the most effective mode in these cases, with P6 stating they would vocally command the robot to move. P8 highlighted their comfort in expressing their needs and emotions to the robot, noting, *“If the robot makes some movement that could lead me to a*

problem... I will say that can you choose another way? Or is there another option...Because I'm not comfortable."

Access to sidewalks was a significant concern for participants, emphasizing the need to **command the robot to leave the sidewalk** through a button or voice command. P9 elaborated, "*The biggest thing for any sidewalk robot is, there [must be] a way for it to get off the sidewalk...*" This sentiment was echoed by P3, P1, and P10, as they felt it could alleviate potential bottlenecks of the curb cut and better accommodate narrower sidewalks.

Addressing robot malfunctions is another circumstance where participants underlined the need for effective interactions. P7 and P8 called for a feature to directly contact operators to address arising issues. However, they also acknowledged that operators might not always be immediately available. In such scenarios, the robots should be programmed to **deliver clear, comprehensible instructions to the public**. This way, bystanders might be more able to assist in mitigating the situation. The guidance could encompass steps to temporarily disable the robot and safely move it out of the way, effectively preventing the malfunctioning robot from becoming an obstacle on the sidewalk.

3.2.2 Exploring the Usability of Interaction Modalities in Public Settings. In pursuit of efficient interactions, we examined the **usability of six potential interaction modalities** in this specific setting: voice interaction, touchpads, buttons, mobile applications, gestures, and wheelchair controllers. Voice interaction and touchpads emerged as popular choices. P5, P6, and P9 lauded voice interaction for its convenience and non-disruptive nature, as it doesn't necessitate pausing current activities. However, P4 raised concerns about the **reliability of voice recognition**, especially regarding accents, fearing this could lead to miscommunication. They preferred an interface-based interaction for its clarity and definiteness, as "*the UX design can give clear instruction and meaning without ambiguity.*" The merits of physical interactions were acknowledged by P1 and P3, who argued that buttons could **distill complex commands into simple, easily understood interactions**.

However, participants also cautioned that direct **contact with the robots might interfere with their personal affairs**, with P10, emphasizing, "*If interaction forces people to stop and spend a significant amount of time, the robots will quickly fall out of favor.*" Balancing the need for effective communication and personal convenience, P8 and P10 favored app-based solutions. They appreciated the non-disruptive and streamlined nature of this modality. This sentiment underlined the potential benefits of gesture interaction. P1 admitted to occasionally using gestures to communicate with other vehicles. They reasoned that if robots could accurately recognize these gestures, this modality could prove helpful in adjusting social distance or directing robot movements.

While participants generally felt less need to interact with robots in non-conflict scenarios, they acknowledged that such **interactions could alleviate anxiety**. Some participants even expressed a desire for casual, human-like interactions with the robots. For instance, P4 said that when a robot passes close by, they would like it to say "*excuse me*" much like another pedestrian would.

4 DISCUSSION AND FUTURE WORK

In this paper, we share an initial set of insights on PWMD's attitudes regarding the design and operation of sidewalk robots in public spaces, a topic warranting further empirical study. We learned that there exist various design opportunities to bridge the gap between sidewalk robots and PWMD, such as social context [16, 23], and accessible interactive methods [7, 9, 17]. For example, future work could concentrate on refining the interaction design of sidewalk robots [12], considering the diverse needs of PWMD [7, 17], and the potential conflict over sidewalk resources [4]. Additionally, research involving a broader participant sample is crucial to understanding the needs and experiences of various demographic groups. Our research brings opportunities to the HRI and Accessibility communities on ensuring that the future of public robots centers on the need for inclusive and equitable pedestrian walkways.

5 CONCLUSION

Our study offers insights into the intricate dynamics between sidewalk robots and PWMD, revealing central themes related to interactions, potential competition for sidewalk resources, and tensions between design factors. We present preliminary insights into how the design forms of sidewalk robots impact PWMD's perceptions of the navigability of public walkways, and how a robot model based primarily on able-bodied data can present challenges for PWMD. We further highlight that enhancing interaction functionalities can significantly improve comfort, trust, and accessibility for PWMD interacting with sidewalk robots. Furthermore, we underscore the importance of considering the unique needs of different interaction modalities.

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Table 1: Summary of Participants' Information

Participant	Age	Motor Impairments	Mobility aids
P1	25	T5 Complete Spinal Cord Injury	Uses a manual wheelchair.
P2	52	Idiopathic Brown-Sequard syndrome	Has walking difficulty; used to but not in a wheelchair anymore.
P3	34	L1 Paraplegic	Uses a manual wheelchair.
P6	36	L1 Paraplegic	Uses a manual wheelchair.
P5	36	Quadriplegic	Uses a power wheelchair.
P7	21	Spastic Diplegic CP	Uses two loftstrand canes.
P4	25	T5 Complete Spinal Cord Injury	Uses a manual wheelchair.
P8	29	C-5/6 Quadriplegic	Uses a manual wheelchair.
P9	19	Physical Disability (TK2D)	Uses a power wheelchair.
P10	35	Spinal Cord Injury	Has walking difficulties.