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Co-designing an Accessible Quadruped Navigation Assistant

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Abstract— **While there is no replacement for the learned expertise, devotion, and social benefits of a guide dog, there are scenarios in which a robot navigation assistant could be helpful for individuals with blindness or low vision (BLV). This case study investigated the potential for an industrial quadruped robot to perform guided navigation tasks based on a co-design model. The research was informed by a guide dog handler with over 30 years of experience of non-visual navigation. In order to communicate spatial information between the human-robot team, two interface prototypes were created and pilot tested: a voice-based app and a flexible, responsive guide handle. The pilot user study consisted of sighted participants and our BLV co-designer, who completed simple navigation tasks and a post-study survey about the prototype functionality and their trust in the robot. All participants successfully completed the navigation tasks and demonstrated that the interface prototypes were able to pass spatial information between the human and the robot. Findings of this exploratory study will help to inform human-robot teaming and collaboration. Future work will include expanding the voice-based app to allow the robot to directly communicate obstacles to the handler, adding haptic navigation signals to the handle design, and expanding the user study to include a larger sample of experienced guide dog handlers.**

I. INTRODUCTION

There is a renewed interest among robotics researchers in exploring the use of agile robots for non-visual navigation guides as the robots have become commercially available and more affordable to buy than to build. With this interest, there are many studies that include Blind and Low Vision (BLV) participants at different stages of the testing process, however, few include people with lived non-visual navigation experience as members of the research team from the inception of the project. More often, researchers may gather data from BLV guide dog handlers to find out their needs, preferences, and concerns at the early stages of the design process or only include them in user testing scenarios rather than establish a long-term research partnership. The term *co-design* refers to the method of designing an assistive technology with individuals who bring their own lived experience to the design, development, and testing cycles [1]. This descriptive case study investigated the potential for an industrial quadruped robot to perform guided navigation tasks grounding the research in an established framework of Co-Design that prioritizes the accessibility expertise of a guide dog handler with 30+ years of non-visual navigation experience as a member of the research team. Based on her specifications and requirements, we developed two interface prototypes that would allow the handler to communicate with the robot guide: a voice-based app and a flexible, responsive navigation guide handle. The case study focuses on the following research questions:

1) *What are the necessary features for a multisensory interface to facilitate critical human-robot interactions for blind navigation in a multilevel indoor environment?*
2) *What human-dog pair navigation behaviors and tasks can be reproduced with an industrial quadruped robot?*

To evaluate the prototypes, we first conducted a usability study with sighted participants to ensure safe operation around the robot. Then, we conducted a descriptive case study with our co-designer-robot team performing a variety of typical navigation tasks in indoor and outdoor settings. This case study contributes insights into the design of accessible interfaces for human-robot teams and provides a practical model for meaningful partnership with expert co-design principles and processes.

II. RELATED WORK

For the 260 million individuals worldwide who have profound vision impairment, non-visual navigation is a daily challenge [2]. Individuals without the use of functional vision typically complete Orientation and Mobility (O&M) training to learn how to navigate independently and safely [3]–[5]. A combination of navigation aids (e.g. canes, guide dogs, human guides) are used with this training, depending on the environmental context [3], [6]. In this case study, we focus on the challenge of human-dog non-visual navigation, providing an overview of the characteristics and essential skills of that form of non-visual navigation pairing. Then, we move on to the design of robots to aid in navigation.

A. Human-Dog Navigation

Approximately 20,000 guide dogs help BLV individuals successfully navigate unfamiliar and complex surroundings in the U.S. [7]. While guide dog schools in the U.S. provide dogs and training to qualified BLV individuals, it is often a year or more wait time to be matched with a guide dog. The cost of breeding, raising, health care, and ongoing training of the dog and their handler can easily reach $60,000, which is often covered by a variety of funding sources [8].

The benefits of guide dogs have been well documented with most studies concluding that guide dogs provide additional social support for their handlers in the form of companionship, bonding, confidence, and protection [3], [9]–[11]. Despite the benefits, there are also significant responsibilities when working with a guide dog, including the costs

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of training, care, and travel restrictions. There is also the emotional toll of separating from a trusted companion after a dog has reached the end of its working time at approximately 6 years. During this transition, handlers must re-apply and undergo extensive training with each new dog as their life circumstances and assistance needs may change [8], [12].

Based on a recent survey of guide dog training programs in the US, most dog training schools begin training at approximately 2 years of age, although socialization training begins with prospective puppies from an early age. There is a standard set of behaviors and skills that all dogs must learn during their 100-150 hours of training before being matched with their handlers [13]. We classify these guide dog behaviors and skills into four main categories (Table 1).

TABLE I: Behaviors Taught at Guide Dog Training Schools [13]

Safe Behaviors:	**Safe Navigation:**
Behave well in public	Work safely in traffic
No aggression to people/animals	safely negotiate “traffic checks”
basic obedience commands	stop at changes in elevation
home when called while off leash	avoid ground level obstacles
intelligent disobedience	avoid overhead obstacles
follow people when commanded	turn and move forward on signal
Transit Skills	**Environment Training**
ride quietly in vehicles	exposed to security checkpoints
ride quietly on public transit	trained in urban environments
navigate changes in elevation	trained in small towns or suburbia
navigate escalators/elevators	navigate nonlinear pathways
navigate revolving doors	find landmarks/objects

B. Robots for BLV Navigation

Early research into the use of robots in non-visual navigation can be traced back to Japan in the 1970’s [14]. Assistive technology researchers have created alternative navigation aids and devices such as smart canes [15], smartphone navigation applications using computer vision systems [16], [17] and robotic guides [18], [19]. Wheeled robots were challenged when confronted with stairs or and other quadruped robots suffered from the inability to communicate, verbal or otherwise, with the handler in a human-robot team scenario [20].

Investigations of quadruped robots as navigation assistants have increased over the last ten years as they have become more agile, easier to operate, and commercially available. Current research investigating the use of quadruped robots for assistive navigation typically use small to midsize robots to simulate interactions between handler-dog pairs. Several Studies have employed [21], [22] used a midsize quadruped robot [23], equipped with a custom handle that is able to receive directional commands from the user. Xiao [24] and colleagues used a smaller robot [25] paired with a longer flexible leash designed to reduce the constraints of a traditional rigid leash in tight corners or narrow hallways. The study paired sighted blindfolded participants with the robot to navigate through a cluttered indoor space. The size of the robots in these studies are smaller than the most common guide dog breeds (Labradors, Retrievers, Shepherds). The robots in these non-visual navigation studies required a longer than typical guide dog handle/harness to connect the human with the robot. This results in non-standard positioning compared to a typical human-guide dog team and limits the critical physical communication between guide and handler.

A few researchers are beginning to explore the use of the Boston Dynamics’ Spot Explorer robot for this application [26]. Spot is commercially available and frequently used in industrial settings monitoring gauges, inspecting equipment for failure points, and constructing maps of factory complexes or mines [27]. Other applications for the robot have a higher public profile and can be seen in advertising [28], entertainment [29], and police/military surveillance [30]. The Spot Explorer robot is considered large among the commercially available quadrupeds [31], approximately two to four times the size of other quadrupedal robots, and a similar size to standard-size guide dog breeds. We used a Spot Explorer model is this study because of its larger size and its existing navigation features.

C. Co-design of Assistive Navigation Technologies

Finding co-designers to form a meaningful research partnership is essential in any investigation of an assistive technology [32]–[34]. This means recruiting expert guide dog navigators at the very beginning of the research and development process, not only as engaged stakeholders or user study participants but as true, longitudinal research partners [35], [36]. Too often, individuals with disabilities are introduced to an assistive technology after the development process has been completed in the user testing phase, not at the beginning where their informed input and design considerations might radically change the course of the research [37], [38]. There may be significant flawed assumptions made by the research team or ‘engineering traps’ inherent in the design based on those assumptions [5]. Individual sensory needs, environmental stimuli processing, and navigation challenges vary greatly for BLV handlers. A research team must include the perspectives, experiences, and design input of as many handlers as possible throughout the development cycle [39].

The principle of co-design is closely tied to the disability rights movement philosophy of “nothing without us” [38]. Our co-designer (and co-author) has over 30 years of experience navigating with guide dogs. Her guidance has made her an invaluable member of our research team since the beginning of the project. Her expertise has informed this research at every stage.

III. CO-DESIGN CASE STUDY: DATA COLLECTION

Our descriptive case study incorporates explicit input, experiences, and values of our BLV co-designer [40]. At the beginning of this process, our team spent time observing human-dog interactions between her and her guide dog. This included discussing verbal communication cues and signals, gestures or body-movement patterns, and targeted behavior rewards that she used to reinforce good guiding behaviors with her young guide dog. The interviews and observations were coded for thematic analysis and followed a deductive process for second order coding [41].

Our co-designer shared that her vision loss was from birth due to Leber's Congenital Amauorsis. She had been a BLV guide dog handler for 36 years, had gone through O&M training and refresher training. Although she preferred navigating with a dog, she uses other aids such as white canes and human guides when necessary. She reported the independence she felt when navigating with her guide dog.

> ”A guide dog is a highly trained, totally dedicated professional...the benefit of a guide dog is the comprehensive impact of the partnership on one's overall confidence and feeling of empowerment... Once being partnered with my guide and achieving more challenging mobility tasks, I started to believe I could overcome other unrelated challenges.”

She reported that her dog was a superior guide to trained human guides who often were unaware of the types of hazards that guide dogs were trained to recognize and avoid.

> ”A sighted human guide may have some training or experience, however, more often they have absolutely none... They often walk at an extremely slow pace while holding their arm at an uncomfortable, unnatural angle, either alerting to every little crack in the sidewalk and shadow or they neglect to alert me to significant elevation changes or announce stairs and dangerous hazards.”

Our co-designer was excited about the potential of a robot guide because she was well aware of the disadvantages of relying only on a guide dog for her mobility and independence. She spoke about the pain of having to retire dogs and find new homes for them, the time invested in training a new dog, and the expenses associated with guide dogs.

> ”The biggest limitation is that guide dogs don't work or live long enough. The average working life of a guide is 6-8 years. While some work longer, and many work less, even 6-8 years is a devastatingly short time. The trust, love, companionship, and depth of communication that develops between a handler and guide is hard won and magnificent. To do that over and over is soul-rending.”

Dogs present serious challenges for their handler when they are sick or injured, such as taking care of their medical needs, when they were unable to work.

> If the handler gets sick or needs surgery... They may not be able to physically care for the guide while recuperating...There are routine costs associated with having a guide dog, not to mention unforeseen emergency ones. With the dreadfully high unemployment and underemployment in the BLV population partnered with guide dogs, this can pose a serious economic barrier to being able to get a dog and afford to keep one.”

We learned about the ways in which the pair passed information to one another, often in subtle ways. There were verbal commands and gestures such as when the dog needed to find and indicate a stair railing. This was rewarded with a treat for the dog since it was a skill they were still working on. There were also body weight shifts and stops to indicate crossings. When asked about the ways in which she communicated with her dog, our co-designer reflected much of what we had observed:

> ”Our primary communication is verbal and hand signals simultaneously or a command given by using movement of the leash or harness. Body position, how the harness handle and leash are held are also part of the non-verbal communication exchange.”

This ability to navigate and communicate in real time comes with experience, practice, and the luck of a good match between dog and handler. The dog anticipates and responds with their body and it is up to the handler to interpret.

> ”The guide indicates all things by either moving their body, which the handler *reads* and follows, or by stopping. When a guide dog stops, it is the responsibility of the handler to immediately stop and investigate the reason. Using a hand, foot, white cane, or possibly a smartphone, the handler explores the area in front of them to find the reason for the guide having stopped. It could be an obstacle, elevation change, travel hazard, or reaching the destination or requested target.”

In some cases, the dog might need to disobey a handler's command if they perceive it could be dangerous such as crossing a street or being urged forward but there is an obstacle or an unexpected hole on the pathway.

> ”If the guide suddenly surges forward, presses backward, or crosses in front of the handler, they are indicating extreme danger such as a dangerously close moving vehicle. The handler has to decide if they should rush ahead, back, or instantly stop while trusting the guide's training in intelligent disobedience.”

Switching the discussion to why she thought a robot guide could be useful and effective as an alternative guide, our co-designer spoke about the kinds of behaviors and skills the robot would need to have to guide. Her assessment of the skills matched the list from the guide dog school survey requirements for a guide dog to receive its credentials. When asked about ways in which a robot might give her different types of information that her dog could not provide, she focused on the robot's potential for verbalizing navigation routes and describing what its cameras were seeing to provide more specific types of spatial information.

> ”The robot having an onboard GPS system would be helpful. Being able to tell the handler the precise location of whatever they have been asked to find.

> For example, if the robot guide was asked to find the bench, it could say, “bench in front of you at twelve o’clock and it is empty.” As more robots have onboard cameras, it seems like they might be able to have the capability to have existing accessibility apps like Seeing AI, AIRA, so those could be used on the fly as the robot guide is working. Being able to announce the existence of the type and location of the obstacle it is stopping for such as overhead, left side, head height, low to the ground.”

Based on the interviews and observations, we designed two interface prototypes that would allow a guide dog handler to interact with a Spot Explorer model as a navigation assistant.

IV. VOICE-BASED INTERFACE PROTOTYPE

The initial prototype consisted of a voice-based smartphone app linked to a Raspberry Pi 4 (RPi4) mounted on the Spot robot. A Swift app was built to take advantage of the iPhone’s robust accessibility features [42]. Spoken commands were transcribed to text using Apple’s iOS Speech Framework and then relayed to the RPi4 using Mosquito (MQTT). MQTT is the leading standard for IoT devices and has a strong presence in robotics [43], [44]. It is a lightweight software solution well suited for environments with unstable networks in which a guide robot might be deployed.

Fig. 1: Voice-based and Touchscreen Interface

The voice-based control prototype was designed with a Handler UI and a backend networked controller. The frontend iOS app provided the handler with an accessible interface to pass simple verbal commands to the robot. The backend served as the control system for Spot and managed all interactions with the robot. In this preliminary study, we used the RPi4 to serve as the backend host and an iPhone 12 to take advantage of Apple’s built-in accessibility features. The iPhone also subscribed as a client, so both components could send and receive information (Figure 2).

Based on existing accessible navigation smartphone apps, the original prototype and its voice-based interactions were designed to control with a combination of finger taps on the screen for initiating and voice to pass commands to the robot. In the prototype, the handler needed to speak the command slowly and clearly, using a short pause between words to help the app transcribe the commands correctly. The Apple Speech framework then transcribed the handler’s command and displayed it on the screen in real time. The interface used a high-contrast start/send command button to accommodate individuals with residual vision who might want to control the text size and high-contrast features. If it was one of the valid commands, the robot would move forward/backward three steps and stop, or move right/left three steps to 90 degrees from its original position and stop.

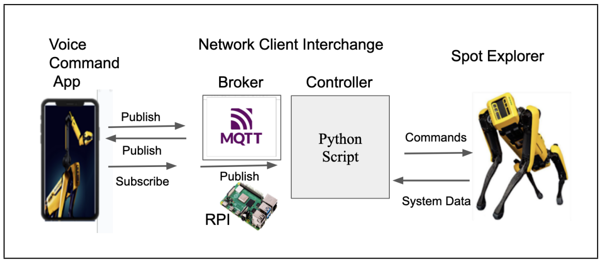
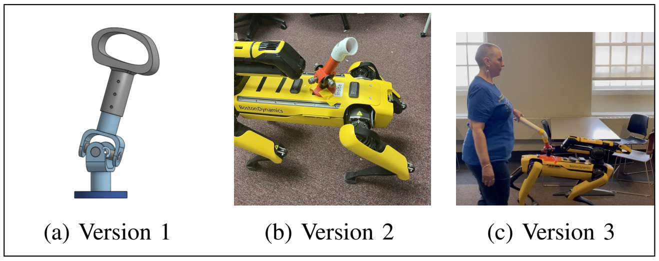


Fig. 2: Voice Interface Architecture

V. HANDLE PROTOTYPE

Standard guide and running harnesses require a strap that is placed around the guide dog’s chest and abdomen. The robot’s rectangular body structure, size, and cameras would be incompatible with these harness systems because the straps would block the front and side cameras needed for navigation. Our co-design handler helped us to locate the exact position in the back rear corner of the robot to stay out of the range of the side camera. This was critical because the robot’s built-in object avoidance system can be triggered when something is positioned below a distance of about 0.075 meters (3 inches) between itself and nearby objects [31]. She also helped us understand the preferred height and angle of the handle prototype that would allow for a handler to walk comfortably with the robot guide.

We designed a custom handle without body strapping that could be positioned on the back of the robot. The first version of the handle was designed using CAD software and was created using a 3D printer. The original design of the handle (Figure 3a) consisted of two forks connected by a universal joint and a handle that was attached to the upper fork. The universal joint created a similar movement as a running harness handle, allowing for a 120-degree turn on both vertical and horizontal movements. The handle was mounted at the rear of the robot’s back to avoid the robot arm and to help the handler stay out of the right-side rear camera view. After early testing, we found the 3D printed U-joint was not strong enough to withstand the amount of force from the robot. The next iteration of the handle shared the same basic shape as the previous version , however, we replaced the 3D-printed u-joint with one made from two metal bolts (Figure 3b) . The metal bolts proved to be more durable than the 3D-printed pieces and allowed for greater freedom of movement for the handler’s wrist. The 3-D printed shaft of the handle was replaced with a short PVC pipe with an elbow curve at the top.



(a) Version 1 (b) Version 2 (c) Version 3

Fig. 3: Handle Prototype

VI. STUDY DESIGN AND METHODS

A pilot user test was conducted for the voice-based interface and the handle prototypes with a group of sighted participants to determine if they could be safely guided by the robot. This might seem like a simple task, however, the positioning of the handle was critical in order to avoid having a handler interfere with the functioning of the side cameras or initiate the robot's object avoidance features while guiding. The sighted participants were asked to give the robot four simple commands using the voice-based interface, complete several simple navigation tasks, and then fill out a short survey evaluating each of the prototype interfaces and assess their level of comfort and confidence during the robot's interactions. We wanted to be sure that the interface prototypes were safe to have humans walking near the robot while holding the handle before we asked our co-designer to attempt the same protocol.

A. *Participants*

The sighted participants group consisted of a convenience sample of 20 undergraduate students and faculty recruited from a liberal arts college through email invitations to the campus community. Participant demographics were not considered an important factor in the analysis, however, slightly more than half of the participants self-reported as female-identifying and the reported age of the sighted participants ranged from 18-60 years old. The only requirement to participate in the pilot was that they were able to walk independently around campus. While there was a range of reported previous exposure to the Spot Explorer robot, only half of the sighted participants reported brief encounters with the robot around campus. None of the participants had used the prototype handle or app, or been guided by the robot prior to their participation in the study. The study protocol and post-study survey were approved by the IRB and all participants completed an informed consent form prior to the start of the study.

B. *Data Collection*

The study protocol began with a practice session to introduce the participant to the voice-based interface and the robot's movements while using the handle while being guided by the robot. During the practice session, the robot was controlled by a researcher using the control tablet and was designed to teach three separate human-robot pair movements: walking forward, turning left and right, and ascending and descending a short flight of stairs. The participants were told they could repeat any of the actions until they felt comfortable with executing the movements with the robot, although most participants did not request additional practice time. Participants were notified what action the robot would take before each part of the practice session. The second part of the protocol included having participants perform verbal commands through the smartphone voice-based interface (i.e., go forward, go backward, go right, go left, stop, stand, and sit). It also included being able to use the handle prototype to guide a handler without running into common obstacles (people, chairs, etc.), lead the handler in a straight line, on a soft curve, and a 90 degree turn to the right/left, stop and then lead the handler up a short set of stairs and back down again. The robot would perform these tasks in auto-walk mode without researcher intervention.

While the user study auto-walk route was pre-planned, the robot needed to make real-time decisions based on new information such as obstacles or approaching humans in a busy hallway setting. The route was similar to a simple indoor path that a handler-guide dog pair might need to navigate daily. To complete the multilevel navigation, the robot needed to lead the participant to the start of a short flight of stairs. Approaching the stairs, the robot would stop and signal to the participant that they were about to go upstairs by lowering its rear down and tipping its front up so that the participant's arm would get raised by the attached handle. After a 3-second pause, the robot would ascend the stairs and then pivot so that its back would be facing down the stairs that it had just climbed. Before descending down the stairs, the robot would once again pause and signal to the user that they are about to go downstairs by raising its back end and lowering its front end so that the participant's arm would be pointed down. After the pause and signaling, the robot descended the stairs. After reaching the bottom of the stairs, the robot turned to the right to lead the participant along the rest of the hallway route and then turned around to walk back to the starting point in the hallway.

The navigation tasks were scored as successful if a participant was able to complete all of the tasks independently with the robot on auto-walk. After completing the navigation tasks, participants were asked to fill out a ten item survey ranking their level of agreement with statements about their experience. The three questions asked about the handle, four questions asked about the functioning of the voice-based app, and the last three questions asked about the participants' feelings of trust and safety around the robot. The Likert scale was anchored from one to five, (1= strongly disagree to 5=strongly agree) and an additional open response question at the end of the survey.

VII. RESULTS

All of the participants (sighted and co-designer) were able to successfully complete the three different types of indoor navigation tasks with the robot in auto-walk mode without difficulty. Results are reported on each part of the protocol.

A. *Voice-based Interface Prototype Results*

The results of the voice interface survey suggest that participants felt they could effectively pass simple verbal commands (forward, backward, right, left) to the robot through the voice interface app prototype and the robot would respond appropriately.

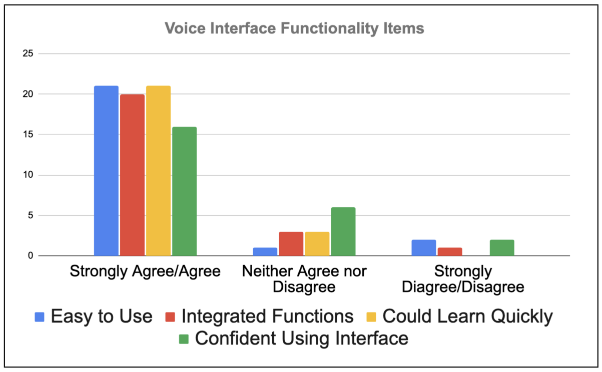


Fig. 4: Voice Interface Functionality

The voice-based interface required the user to state the exact prompt once the voice command button was enabled on the smartphone. If the prompt was not clear or incorrect, the robot did not respond. All of the participants were able to complete the voice prototype trial even though they may have had to repeat a command if necessary.

B. *Handle Prototype Results*

All of the participants were able to complete the auto-walk part of the study using the handle without difficulty. Participants reported they found the handle easy to hold and comfortable, and they could feel the robot guiding them through the handle (Figure 5). There was less agreement about the smoothness and stability of the handle. The open-response question asked for feedback about how the handle could be improved. Participants noted they a better grip on the handle, in order to go down the stairs smoothly.

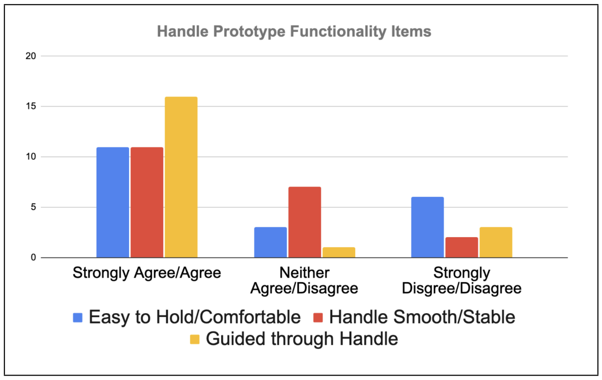


Fig. 5: Handle Survey Responses

C. *Trust and Safety*

Overall, participants reported a high level of trust in the robot's ability to guide them and that they felt safe both just being around the robot and operating the robot during the navigation tasks. There were several sighted participants who reported in the open response question that they had slight safety concerns about being led by robot despite successful navigation. (Figure 6).

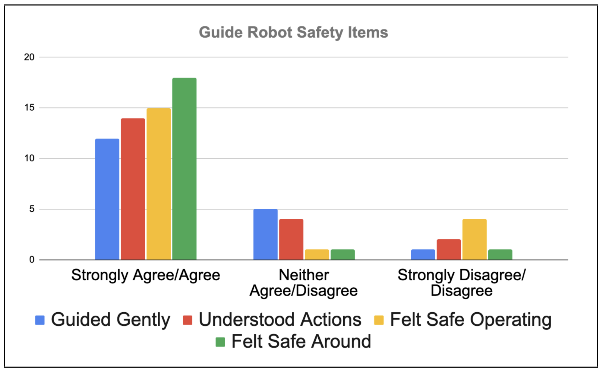


Fig. 6: Robot Safety Survey Responses

VIII. DISCUSSION

This case study investigated the potential of a commercially available, industrial quadruped robot to operate in a human-robot team to complete assistive navigation tasks that would be typical of a handler-guide dog pair. While there are other types of quadruped robots being investigated as navigation assistants, they often encounter issues based on the lack of an effective interface that facilitates communication of commands and spatial information between the handler and the robot guide. Through a series of interviews, design sessions, and testing with our co-designer, we implemented a voice-based interface for the handler to give verbal commands to the robot through an iPhone app. We also created a flexible handle that allows the handler-robot team to communicate spatial information related to the robot's expected trajectory, unexpected object avoidance, and changes in elevation. The next section will address the research questions and the sighted participant and the co-designer user studies.

What are the necessary features for a multisensory interface to facilitate critical human-robot interactions for blind navigation in a multilevel indoor environment?

All of the sighted participants in our human-robot pairings could perform simple guided navigation tasks as human-robot teams. The prototype handle proved an effective way for participants to receive information about the robot's body motions allowing them to feel comfortable with being led through the study route and tasks. The full rotation in 3 dimensions allowed the participant to move with the robot during changes in direction and angle during turns. The positioning of the handle on the rear of the robot's back, combined with a slightly longer handle stem, allowed the participant to be guided by the robot without interfering with the robot's side cameras.

Participants indicated the robot could easily guide them through an elevation change (i.e., short flight of stairs) even though the robot needed to pivot to go down backwards. Our co-designer also had the robot guide her along the same simple indoor route and a more extensive outdoor route. The robot was able to guide her around pedestrians, puddles, and suitcases while remaining on the sidewalk in auto-walk mode. The only adjustment we made to her indoor and outdoor trials was to move the robot to a medium speed setting at her request because she said it was walking too slowly for her to be comfortable as it was much slower than her guide dog's normal pace.

This preliminary study did not use the wide range of built-in features or navigation functionality available in this advanced robot, nor did we implement the extensive object detection models that would allow for more complex autonomous routes to be tested. Instead, we focused our attention on developing two early prototypes for the human-robot pair to communicate with one another through non-visual channels (handle and the voice app). The multisensory interface prototypes worked well enough for the participants to give the robot a set of simple voice commands through a smartphone app and have the robot respond. The high contrast button allowed for visual interaction and the keyword-based audio interface worked to pass the robot the commands over the network. While there were some instances of the participant having to repeat the command more clearly or precisely to enable to app to pass the command to the robot, it worked well enough for this early trial to warrant further development.

What human-dog pair navigation behaviors and tasks can be reproduced with an industrial quadruped robot?

For blind navigation in a multilevel indoor environment, critical human-robot communication interactions are vital in ensuring safe and effective non-visual navigation. Minimally necessary interactions between a human-robot pair were understanding of each other's movement intentions, the ability to avoid danger and obstacles, and making decisive decisions for the user. The Spot Explorer model is able to perform such tasks to varying degrees. With respect to communication between the user and Spot, there is good one-way communication where Spot is able to guide the user effectively through the handle. The participants were able to understand Spot's actions. However, beyond the movements from the handle, there are minimal forms of communication from Spot to the handler such as the hand gestures or harness movement signaling between a handler and their dog. Guide dogs must make active decisions for the handler in the event that the handler's actions may result in harming them; this is known as intelligent disobedience. Therefore, the research and development of an agile industrial robot for navigation assistance still has a long way to go before it is ready for deployment in a real-world setting.

IX. LIMITATIONS

While this case study provided valuable initial information, it had several limitations. We relied heavily on sighted participants as the early user population due to the lack of BLV guide dog handlers around the rural area of the college. Furthermore, even this sighted population that participated in the study had a relatively small sample size (n=20). The small number of participants makes it difficult to generalize conclusions but it did allow us to evaluate if the robot was safe to operate in autowalk mode using the prototype handle. In addition, as they were sighted, they could maneuver themselves around obstacles or step away from the robot if the robot was trying to avoid obstacles, thus increasing their sense of control and safety in a set of simple navigation tasks. This problem is most prominent when Spot transitions from going up to down the stairs. It is recommended that the robot to go down the stairs backwards. This requires Spot to pivot and for the user to switch hands or pivot along with the robot. There may also be some inherent bias regarding trust in robot safety as the participants in the study were volunteers, and some had seen the robot previously being used in research on campus. Finally, the majority of our participants were sighted and, therefore, not familiar with standard guide dog-handler communication techniques. They were unable to provide a full range of feedback on the effectiveness of the communication through the handle as a part of the human-robot pair in the same way as our BLV co-designer.

X. CONCLUSIONS AND FUTURE WORK

This case study investigated an industrial quadruped robot as a potential non-visual navigation assistant. The selection of a large industrial robot was based on its similar size to common guide dog breeds and its built-in navigation abilities. We worked with our co-designer to identify the robot's potential benefits and limitations, and the human-robot pair behaviors necessary for simple guided navigation tasks. We developed two non-visual interface prototypes for the human handler to give and receive spatial information from the robot: a voice-based interface to give the robot commands and a guiding handle that allowed the handler to coordinate their strides and direction with the robot guide. We found that the robot could reproduce simple navigation actions similar to a guide dog, and the interface prototypes provided a basic level of communication and interaction between the handler-robot pair (voice, handle motion cues). However, we also identified several limitations based on the robot's current design and existing programming. The results of this descriptive case study and observations suggest that the interfaces allowed sighted and blind participants to give basic verbal commands and understand the robot's actions and movements through the handle. Future work includes streamlining the handle design with new haptic features, a two-way verbal human-robot interface, and making adjustments to the robot's pacing and acceleration.

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