Lessons Learned from Developing a Human-Centered Guide Dog Robot for Mobility Assistance

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Abstract

While guide dogs offer essential mobility assistance, their high cost, limited availability, and care requirements make them inaccessible to most blind or low vision (BLV) individuals. Recent advances in quadruped robots provide a scalable solution for mobility assistance, but many current designs fail to meet real-world needs due to a lack of understanding of handler and guide dog interactions. In this paper, we share lessons learned from developing a human-centered guide dog robot, addressing challenges such as optimal hardware design, robust navigation, and informative scene description for user adoption. By conducting semi-structured interviews and human experiments with BLV individuals, guide-dog handlers, and trainers, we identified key design principles to improve safety, trust, and usability in robotic mobility aids. Our findings lay the building blocks for future development of guide dog robots, ultimately enhancing independence and quality of life for BLV individuals.

Keywords

Accessibility, Robotic mobility aid

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1 Introduction

Over 36 million people globally and one million in the U.S. live with severe visual impairments, a number expected to double within the next 30 years [1, 17, 33]. Guide dogs are one of the most effective mobility aids to support the independent mobility of blind or low vision (BLV) people [27, 34]. Extensive studies have highlighted the benefits of guide dogs compared to other assistive methods (*e.g.*, white canes) in terms of mobility, independence, and enhanced confidence [42, 49, 55, 72]. However, only a small portion of BLV people have access to guide dogs, mainly due to the limited supply [18]. Training a guide dog requires over $50,000 and approximately two years. The limited supply is further strained by the short working lifespan of guide dogs, typically less than ten years, often resulting in wait times of up to two years for acquisition [19], a challenge that became even more pronounced during the COVID-19 pandemic. Even after adoption, handlers are responsible for lifelong care and maintenance, including medical care, feeding, and daily walks. Additional health and personal factors, such as allergies to animals or limited living space, can further complicate the adoption of a guide dog. Despite their significant benefits, guide dogs may not be a scalable or sustainable solution for the larger population of BLV people.

Motivated by recent progress in quadruped robots and their potential for mass production and long-term sustainability [14, 70, 75], we aim to create a practical guide-dog robot as an additional solution for navigation assistance for BLV people. Unlike wearable or hand-held devices [4, 11, 13, 16, 28, 35, 41, 53, 57, 59, 61, 62, 65, 66, 69, 71, 76, 77], which require users to scan their surroundings actively, quadruped robots can offer complete local navigation, significantly improving ambulation speed, safety, and comfort [12, 42, 48]. Mobile robots for navigation assistance have been studied for 40 years, beginning with wheeled systems [21, 25, 36, 38, 45, 50, 63, 64, 67, 68] and more recently moving to quadruped robots [7, 9, 15, 26, 51, 74]. Compared to wheeled systems, quadruped robots offer superior traversability that enables navigation through uneven terrains and heterogeneous structures (*e.g.,* stairs and curbs) in real-world environments.

Despite a long history of mobile robot research, none have been deployed for BLV individuals due to a limited understanding of how guide dogs and their handlers work together in real life. For example, some robots are too bulky for various situations such as public transportation or crowded areas [15, 26, 51] that can be easily seen in urban environments. Also, challenges such as inappropriate leash systems, improper handler positioning, and overemphasis on autonomous navigation without addressing user adoption have hindered development [32, 74]. To understand how navigation is performed by people with BLV, we need to distinguish between

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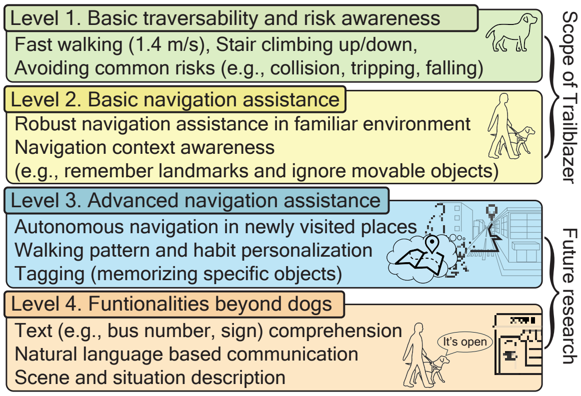

Figure 1: Development roadmap for the guide dog robot.

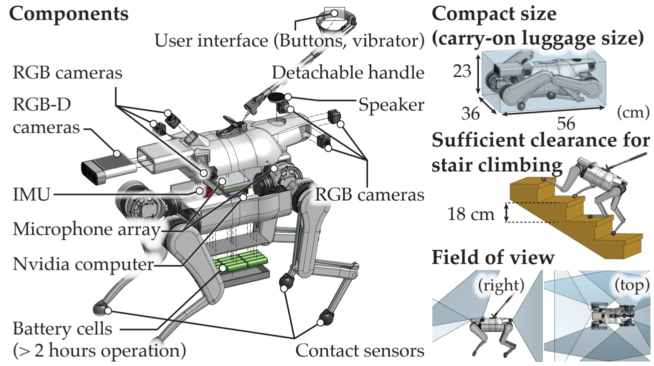

Figure 2: Concept drawing of a guide dog robot.

the two roles that constitute the navigation task: *Orientation* and *Mobility* [73]. Handlers are responsible for *orientation*, which involves knowing and executing routes, and making key navigational decisions, such as turning or crossing a street at waypoints. On the other hand, guide dogs take on the *mobility* role, ensuring the handler's safety by detecting and avoiding collisions with pedestrians or objects such as trash cans, cars, or bicycles [23].

Misunderstandings about basic human-guide dog interaction are also common. For example, systems proposed by [9, 37, 74] employed a soft leash, which is problematic as handlers must use a rigid harness handle to perceive immediate feedback about the guide dog's motion [25]. In another study [7, 26], the handler was positioned behind the robot during navigation, whereas a guide-dog handler should be positioned next to the dog for safety and efficiency. Some studies address technical problems that are less critical or unimportant for assisting navigation for BLV people. For example, [26] focused on enhancing the locomotion stability of quadruped robots, although our study measuring the pulling forces of guide dogs indicated that even the robot's default controller can sustain the forces [32].

To avoid such mistakes and design an effective guide-dog robot, we propose a *human-centered approach* and share insights gained from our previous work, which includes an iterative process of 1) technology development, 2) evaluation via human experiments, and 3) refinement via formative studies. Our prior studies [30–32], including semi-structured interviews with 23 blind guide-dog handlers, 6 BLV individuals, and six experienced trainers, along with several observational and participatory sessions, led us to identify critical design criteria and technical challenges, and build a roadmap for guide-dog robot development as described in Fig. 1. With a vision where quadruped robots are ubiquitous, this project ambitiously seeks to establish the standards for guide-dog robot design and development, ultimately enhancing independence and quality of life for BLV people.

2 User-Centered Insights

The successful completion of this project aims to shift the focus of guide dog robot research from a technology-centered approach to a human-centered one. Rooted in our comprehensive understanding of the interaction between guide dogs and their handlers, we share lessons learned throughout the development process such as 1) new quadruped robot hardware featuring compactness, portability, extended operation, and multi-modal sensing; 2) a co-optimization framework for robot hardware and controllers to create an energy-efficient and comfortable navigation assistant for BLV people; and 3) a robust navigation system that adapts to scene variations based on our learning framework utilizing multi-sensory data and foundation models.

2.1 Understanding handler-guide dog interaction and Trust

In our prior work [30], we conducted a thematic analysis of interviews and observations to investigate guide dog–handler interactions. This revealed: (1) limitations within these interactions, (2) continuous interactions tailoring to meet handlers' specific needs, and (3) expectations and concerns about robotic guide dogs. We found that trust is cultivated over time for guide dog handlers and strong trust is built through long-term positive experiences. Therefore, achieving autonomy requires overcoming hurdles not only in technology development but also in user adoption. Another important aspect to consider is that the orientation role is gradually delegated to the guide dog as they become familiar with the environment [30].

2.2 Optimal guide dog robot hardware and locomotion controller

Commercially available small-scale quadruped robots [14, 70, 75] offer potential as research platforms but face significant limitations as guide dog robots due to their form factor, sensor suite, battery life, and locomotion control. Their short legs limit ground clearance, preventing stair climbing, and larger robots are impractical for public transport, where guide dogs must fit under seats and be portable (*e.g.,* fit in a carry-on baggage) [25, 30]. Additionally, current sensors lack the field of view needed to detect overhead obstacles or account for occlusions caused by the user's proximity. Battery life is another critical issue—while some robots claim 2–4 hours of operation [56], real-world tests show less than an hour, and added sensors further reduce this [32]. Furthermore, the noise and vibration caused by current locomotion controllers disrupt the auditory and haptic feedback critical for BLV users [8]. Addressing these issues, we aim to design a quadruped robot optimized for BLV assistance as depicted in Fig. 2.

Recent advancements in reinforcement learning (RL)-based locomotion control [10, 29, 40, 47, 81], have shown impressive agility and robustness in quadruped robots. However, prior work has paid little attention to achieving gentle and quiet walking, and existing RL approaches have not addressed the coupled relationship between hardware design and locomotion control. To optimize both, we believe that a RL training framework that simulates multiple robot designs with randomly sampled parameters, searching for the best locomotion policy in parallel [58] can iteratively refine design configurations until the optimal hardware and controller for gentle walking are identified.

2.3 Foundation model-based robust navigation

Although mobile robot navigation has a rich history of research [5, 6, 43, 44], existing approaches rely heavily on building detailed maps, continuously updating them, and requiring significant computational resources for real-time localization [39]. These requirements pose significant problems, not only because data gathering, labeling, and updating are time-consuming and economically expensive, but also because the high computational demands are difficult to accommodate in a guide-dog robot with limited size and battery power. Additionally, the top-performing algorithms in localization benchmarks such as KITTI [22] rely on LiDAR sensors, which are expensive and heavy for integration into a guide-dog robot. On the other hand, state-of-the-art visual localization and mapping solutions, which do not rely on such sensors, are still not robust enough to handle the scene variations that will be encountered by a guide-dog robot in real-world environments [46, 54]. Relying on conventional metric localization and mapping for the guide dog robot setting is thus impractical, given the robot's limited computational resources and payload, and the stringent robustness needs of the application.

However, we have a key insight that can help us sidestep these challenges. Instead of solving the general-purpose navigation problem (*i.e.,* driving from any point A to point B), we aim to develop a navigation system capable of recording desired routes and recalling the demonstrated paths without building a meticulously tailored global map or accurately estimating the robot's position. This navigation setup is called the 'route-recall' or 'visual teach and repeat (VT&R)' problem [78] (see Fig. 3). The way VT&R formulates the navigation task resembles how a guide dog learns a new path: by repeatedly traveling specific routes under the supervision of a sighted person. From an algorithmic perspective, VT&R relies less on localization accuracy and is computationally cheaper since navigation actions are determined based on memorized scenery and rough position sequences, similar to how humans (or animals) navigate previously visited places [24].

While promising, we need to address issues related to scenery variations between demonstration and recall. Reasoning about *semantics* is key to robustness – when memorizing a path, the robot should focus on objects that are most informative about progress along a route, such as detecting road intersections, notable buildings, or specific stores, while ignoring less informative objects like

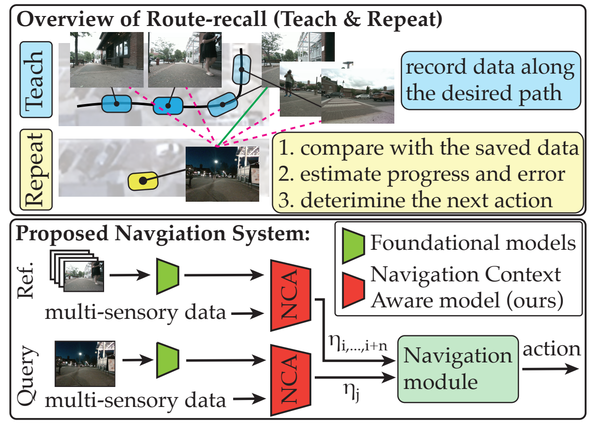

Figure 3: Overview of the proposed navigation system.

parked cars or trash cans [2, 80]. Recent advances in visual foundational models (*e.g.,* DinoV2 [52]) have shown great promise in understanding general-purpose semantics in images and are robust to lighting variations and viewpoint changes. However, these models are not optimized to understand the *navigation* context, which is crucial for route-recall navigation. To overcome these challenges, we are developing a VT&R navigation system, using a self-supervised learning framework that integrates foundational models — renowned for their ability to interpret general-purpose semantics and adapt to changes in lighting and perspective — and exploring methods that utilize large-language models (LLMs) [3, 60] and disentangled representation learning that may allow the robot to differentiate between critical and non-essential variations, improving its reliability in dynamic environments and enhancing the practicality of guide dog robots for BLV users.

Unlike fully autonomous guide dog robots, which may not be ideal during initial interactions [79] due to potential trust biases [20], we believe that a VT&R pipeline can foster a more natural development of trust. Just as novice guide dog handlers initially struggle to trust their guide dogs but gradually form strong, reliable bonds, we envision a similar trajectory for guide dog robots. Through repeated exposure and consistent performance, this approach has the potential to cultivate trust progressively, ensuring a smoother transition, ultimately enhancing the user experience through autonomy.

3 Conclusion

In conclusion, this work highlights the crucial need for a human-centered approach in developing guide dog robots to meet the real-world needs of blind or low vision (BLV) individuals. By integrating insights from interviews, guide dog-handler observations, and early development, we identified key principles in hardware design, navigation, and user trust. These findings provide a foundation for future research, focusing on optimizing quadruped robots and leveraging advanced learning models for robust navigation. Our findings offer a clear roadmap for the continued development of guide dog robots, with the potential to significantly enhance the independence and quality of life for BLV individuals through scalable and reliable mobility solutions.

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