Field Trials of Autonomous Navigation Robot for Visually Impaired People

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Figure 1: Field trials were conducted using *AI Suitcase*, an autonomous navigation robot designed for blind and visually impaired individuals: a) pilot study at a commercial complex; b) permanent daily operation at a science museum; and c) testing an outdoor model.

Abstract

Despite the advances made in assistive technologies for people with visual impairments, challenges remain in unfamiliar public spaces such as shopping malls, museums, and transit hubs. First-time visitors often face difficulties in navigating these environments independently, so they seek both safety and ease. To address this issue, we developed AI Suitcase, a navigation robot that resembles a conventional suitcase. By holding its handle, users are guided safely to their destinations while receiving real-time information about their surroundings, promoting mobility and independence for individuals with visual impairments. This paper presents the results of field trials from a pilot study in a commercial complex, daily operations at a museum, and an outdoor pilot test, involving more than 2,200 participants, a quarter of whom are visually impaired. Positive feedback and interest in using navigational robots in daily life suggest the potential of this technology. The challenges encountered during these trials, which are crucial for practical deployment, are also discussed.

CCS Concepts

• **Human-centered computing** → **Accessibility systems and tools**.

Keywords

Accessibility ; Navigation ; City ; Robot ; Experience Sampling ; Field Study

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1 Introduction

Activities such as shopping, going to school or cultural institutions, and using public transit hubs or other public places are crucial parts of our social life. Blind and visually impaired individuals (BVIs) face difficulties in navigating these environments due to the challenges of acquiring information on obstacles, corners/turning points, pedestrians, and signs, as well as other visual information at these public places. An important aspect of mobility for sighted individuals is enjoying urban environments, such as spontaneously stopping at shops they come across. However, these basic activities can be challenging for BVIs.

Historically, various methods have been developed to support mobility. Among them, white canes stand out as the most widely used, enabling users to detect walls, obstacles, and landmarks. While navigating familiar routes becomes possible, visiting unknown places with only a cane is challenging. Guide dogs are trained to avoid obstacles and indicate turns, but they do not understand destinations, requiring their human partners to make directional decisions. Nevertheless, despite their limitations, white canes and guide dogs have long supported the mobility of BVIs.

In recent years, numerous navigation systems for BVIs have been proposed, using a variety of technologies such as smartphones [3, 15, 17], audio augmented reality [7, 23], smartcanes [10, 21], and autonomous mobile robots [6, 18, 22]. Notably, navigation robots, including guide dog robots, have the significant advantage of enabling BVIs to simply follow and reach a designated destination autonomously [6, 18, 22]. Users can move with ease and less cognitive load compared with existing methods. Many such concepts have been proposed, but most remain at the research stage, with few advancing to prototype testing [19].

Our team has also developed a navigation robot, *AI Suitcase*, designed to emulate the form of a conventional suitcase. This robot allows BVI users to interactively select their destinations and then guides them there autonomously and safely. This project began in 2017 at Carnegie Mellon University with a prototype called CaBot [5, 20], and after several improvements, it has evolved to its current form. We have applied AI Suitcase as a platform for research in advanced navigation and social acceptance [8, 9, 11]. In addition, we have conducted a series of field trials to evaluate its effectiveness in assisting BVI individuals in real-life settings.

This paper describes AI Suitcase and its field trials. We focus on three key trials: a pilot study in a commercial complex, daily operation at a museum, and an outdoor pilot test. These trials involved around 2,200 participants as of September 30, 2024, a quarter of whom were visually impaired. Finally, we discuss critical challenges of implementing navigation robots like AI Suitcase.

2 AI Suitcase

The development of AI Suitcase began with the aim of creating a navigation robot that could be socially implemented while leveraging the advantages of robots. The reason for its suitcase-like shape is primarily due to its ergonomically refined design, which makes it easier to walk with. When the robot is pushed forward, it naturally encounters obstacles like corners or downward stairs in front of the user, which increases the user's safety. In addition, someone walking through the city with a suitcase is a common sight, allowing the user to blend seamlessly into the urban environment. Consequently, the concept of a suitcase-shaped navigation robot incorporating recognition, control, and drive systems was envisioned.

One of the key challenges in making robots practical is ensuring that they can be naturally integrated into the user's daily life. Our design prioritizes enhancing user convenience and social acceptance without compromising functionality. For example, instead of incorporating complex and costly mechanisms to overcome steps, we adopted a suitcase-shaped device that allows users to lift the robot over obstacles when necessary, just as they would with a regular suitcase. This approach strengthens the interaction between the user and the robot, supporting comfortable mobility while promoting independence.

The design principles of AI suitcase are as follows.

(1) Ensuring user trust: It achieves trustworthy safety by effectively avoiding obstacles and pedestrians, thanks to its numerous sensors and ample computing power.
(2) Allowing users to enjoy it: The robot strives to enhance the user's experience by providing information about the surrounding environment.
(3) Seamlessly blending into urban environments: Modeled after a suitcase, the robot's design allows BVI pedestrians to smoothly blend into urban settings.
(4) Simplified operation: The robot features intuitive operation methods via hearing and touch senses, making it easy to use even with minimal training.
(5) Prioritizing user comfort: Ergonomically sound, the carry-on suitcase shape enables users to interact with it in a natural posture without experiencing stress.
(6) Adhering to social norms: The robot is programmed to adhere to social rules, such as queueing appropriately instead of cutting into line.
(7) User assistance when needed: The design principle involves users assisting the robot with tasks it cannot perform, such as overcoming steps.

2.1 Examples of Implementation

Several models of the AI Suitcase have been developed[1]. Figure 2 shows the basic system of the indoor model developed in 2022 and the outdoor model in 2023. The main body utilizes a commercially available suitcase of a size suitable for carry-on luggage on a plane. We selected a product that is four-wheeled and can be reinforced internally with frames. The most significant visible differentiation in its conversion from the original suitcase to the robot's body

[1]IROS 2022 Plenary Talk 2: Chieko Asakawa – Navigation Robot for the Visually Impaired, https://youtu.be/dNE7XuNGXk0

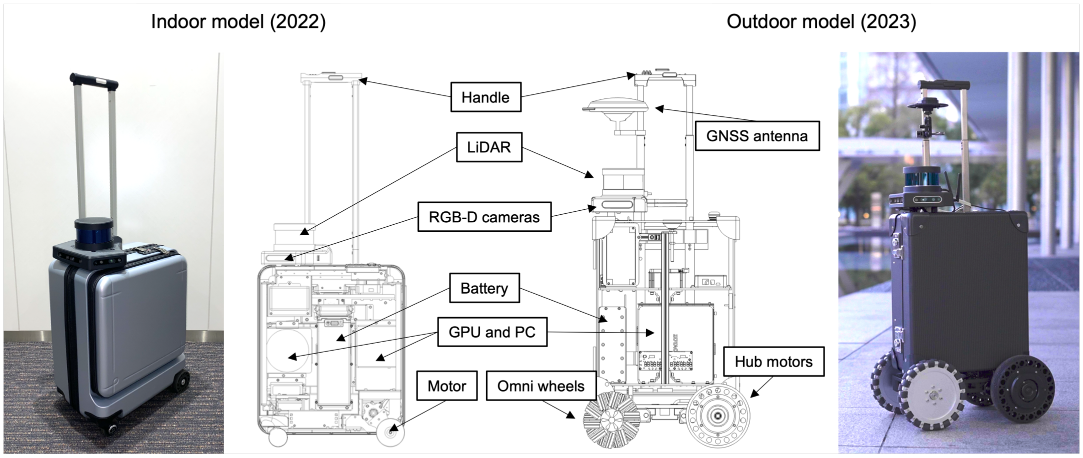

Figure 2: AI Suitcase's Architecture (Indoor Model and Outdoor Model)

would be the sensors mounted on its top. The weights of the indoor and outdoor models are around 15 kg and 30 kg, respectively.

2.2 Interaction with AI Suitcase

Users interact with the robot through its customized handle, and their smartphones connect wirelessly to the robot's system. A touch sensor located under the handle activates the movement mechanism, which ensures that the robot only moves when the handle is touched. Consequently, releasing the handle stops the robot, preventing uncontrolled movement and providing intuitive control.

Additionally, there are vibration-based notification devices at three locations: the top and both lateral sides of the handle. Early experiments in development revealed that users felt uneasy when the navigation robot suddenly made turns while guiding them[5]. Therefore, a mechanism that provides prior notification through vibrations at the sides before making a turn was introduced. Before starting and stopping, notifications are also provided through vibrations by the top device.

A smartphone is used for interaction such as destination selection and verbal guidance. We use smartphones because they have been widely adopted among BVIs, which allows the users to start using the interface without training. On the initial screen, the top menus offer options for "Start Conversation" for conversational destination selection via speech, and "Select Destination," which leads to the selection menu screen through standard app operation. The third menu, labeled "Select Tour," indicates that the robot will guide a user to a sequence of destinations, such as a series of exhibits at a museum.

3 Field Trials

Field trials were conducted at various public places, involving more than 2,200 participants, approximately a quarter of whom were visually impaired. At the beginning of all field trials, we informed the participants that the primary purpose of the experiment was to collect feedback on their experience with AI Suitcase and that the feedback obtained would be used for future research and development. These field trials are described in the supplementary materials. In this section, we overview the results of a pilot study conducted in a commercial complex, daily operations at a museum, and an outdoor pilot test.

3.1 Indoor Pilot Study at Commercial Complex

3.1.1 Overview. The Nihonbashi Muromachi area features large commercial facilities located along a 300-meter-long underground passage. This underground passage is a complex environment with sections owned and managed by different entities, including subway operators, building owners, and the national government. This fragmented ownership structure necessitated obtaining separate permissions for each section to conduct the trial. Obtaining permission required addressing key safety and privacy concerns. To ensure safety, an engineer had to accompany the experimental robot at all times. Furthermore, video recording was prohibited in certain areas with high pedestrian traffic or commercial activity to protect the privacy of individuals. Despite these challenges, we successfully obtained the necessary permissions and conducted the trial in this dynamic underground environment.

The trial area covers $31,360m^2$ across five commercial facilities, and it encompasses 150 stores. Between September and October 2022, each field trial was conducted by allowing free selection of stores for navigation lasting between 30 minutes and an hour. A total of 38 BVIs participated, with 6 in a preliminary experiment and 32 in the main trial[2]. In the main trial, the participants' ages ranged from their 20s to their 70s, with a gender distribution of 20 females and 12 males. Among them, 28 participants were classified as legally blind under Japanese standards [13].

3.1.2 Results. Post-trial surveys reveal significantly higher favorable responses in six main indicators: preference for future use, confidence in not getting lost, feeling safe, confidence in mobility, lack of stress, and enjoyment in comparison to navigation methods using smartphones [13]. Comments included positive feedback such as *"It felt very easy as I just had to follow it," "I expected to get lost more, but it was smoother than I thought," "I felt a sense of accomplishment and liberation from not having to carry a white cane,"* and

[2] AI Suitcase Experiment at Nihonbashi Muromachi, https://youtu.be/KU1x1Vv0Fgg

"I was thrilled to walk long distances and experience window shopping." These results confirm that our system achieved various design goals such as ergonomics, short training time, and enjoyment as listed in Sec.2.

By comparison with the users' perspectives on guide dogs, comments received included *"Following it was easier than with a guide dog because it required no special care"* and *"It's easier to manage."* On the other hand, users volunteered criticisms such as *"It stops too much when pedestrians are present, while guide dogs make quicker decisions"* and *"Guide dogs can navigate steps."* The concern regarding steps highlights an aspect that had been intentionally simplified in the design.

One of our goals is to provide information about the surrounding environment, such as shops and various establishments, to enable BVI users to enjoy urban environments. To achieve this, we created static information of the PoIs (points of interests) at trial fields based on web data. However, there were demands from users that such information could not satisfy. For example, users expressed a need for real-time information such as "want to know products currently on sale" or "want to know seasonally limited products." In addition, there was a need for handling searches based on specific product types, such as "want to buy handkerchiefs," that could not be adequately completed through web searches alone.

Suggestions for improvement included the desire for smoother movement, since abrupt starts and stops were occasionally experienced. Consequently, these issues have been addressed in subsequent improvements to the software. Challenges with the time-consuming elevator boarding and exiting were also raised, but these involve technological complexities with door sensing and recognizing human movements, requiring ongoing research and development.

No accident leading to the suspension of a trial was reported. However, there were near-accidents, such as instances where participants nearly bumped into passersby who were walking nearby at high speed without noticing the participants' presence. Avoiding pedestrians who approach quickly without being aware of the robot remains a significant, if not impossible, challenge. There were also moments when the robot nearly collided with glass doors, signs, or tables, highlighting limitations in the LiDAR technology. Data on these instances continue to inform ongoing software improvements. An accompanying engineer always followed behind the robot and the user with a laptop, ensuring the user's safety during these near-accident situations. These engineers also provided timely support for technical troubleshooting when necessary.

3.2 Daily Operation at a Science Museum

3.2.1 Overview. Miraikan, also known as The National Museum of Emerging Science and Innovation, is Japan's premier science center, with exhibition floors spanning 11,000 m^2 within a seven-story building that occupies 40,000 m^2. After joining the AI Suitcase Consortium in 2021, we conducted a series of short-term trials and worked to improve the robot's hardware and software for safety and robustness. Following two and a half years of enhancements, Miraikan officially launched permanent daily operations on April 18, 2024. This deployment aims to allow both blind and visually impaired (BVI) visitors, as well as sighted visitors, to experience AI Suitcase, with its vision becoming a tool for fostering inclusivity in future urban environments. One key objective is to familiarize sighted visitors with the robot, its operations, and its safety, helping to reduce psychological barriers associated with autonomous assistive navigation robots. Enhancing social acceptance is essential for successful societal implementation. Currently, there is still a lack of understanding of autonomous robots equipped with various sensors that navigate independently through crowded public spaces. By building a track record of daily operations and providing opportunities for sighted visitors to experience autonomous navigation robots firsthand, this initiative aims to help improve the social acceptance of such systems.

As visitors moved through the museum, they received audio explanations providing an overview of upcoming exhibits, allowing them to explore the museum while considering the content of the exhibits. The robot also provided detailed explanations for selected accessible (touchable) exhibits. Figure 3 shows an example of reading text for the hands-on models of a human fetus at different developmental stages, from a fertilized egg to about 32 weeks.

For daily operation, we developed a smartphone application that allows museum staff, who may lack technical expertise, to operate the robot without needing the assistance of researchers or engineers. The application's main functions include starting/stopping AI Suitcase, monitoring the system and device status, setting and verifying destinations and tours, reviewing the audio being heard by users, and uploading both robot and application logs with staff comments when problems occur. As a result, compared to the field study in Sec. 3.1, the system became much more robust and easy to operate, allowing non-technical staff to support it instead of depending on an engineer to continuously check the system.

3.2.2 Process of the AI Suitcase Experience. Figure 4–a shows floor maps of the museum. Visitors first check in at the AI Suitcase Station located on the third floor, which serves as both the starting and finishing point for the AI Suitcase experience. Visitors can choose from two tours: **(1) Predefined Tour (*Planetary Crisis Tour*):** This tour provides an experience of the "Planetary Crisis" exhibit, which opened in 2023 and features a theater and interactive displays that allow visitors to experience rising global temperatures and CO2 emissions from various countries. This tour is suitable for participants with visual impairments who wish to experience the science museum. The tour takes approximately 25 to 40 minutes. **(2) Free Choice Tour:** This tour allows participants to choose and explore about three exhibits from all of the exhibits in the permanent exhibition area (3rd and 5th floors). This is suitable for participants who already have a desire to see specific exhibits or who are primarily interested in experiencing navigation with the AI Suitcase. The tour takes approximately 15 to 20 minutes.

3.2.3 Results. From its launch on April 18, 2024, to September 30, 2024, 1,288 people experienced AI Suitcase. Of these, approximately one fourth were estimated to be visually impaired. Table 1 shows the results of the questionnaire survey conducted up to June 30. The number of responses does not match the number of participants because some groups experienced the tour together and submitted a single questionnaire. "Visually impaired" refers to the number of respondents who explicitly stated they have a visual impairment,

"In this exhibit, you can physically experience the stages of fetal development from a fertilized egg. There's a shelf approximately one meter wide, positioned around waist height. On this shelf, there are seven circular plates arranged horizontally, each containing a life-sized model representing various stages of fetal growth."

"Starting from the left, let's begin with the fertilized egg. It's incredibly small, with a diameter of about 160 micrometers."

"Moving to the right, the next model represents the fetus at 19 days. At this point, the emergence of red blood cells can be observed."

…

"Additionally, there's a model on the wall depicting a fetus approximately 32 weeks post-fertilization, providing a glimpse into the later stages of development."

Figure 3: Example explanation for hands-on models of a human fetus at different developmental stages

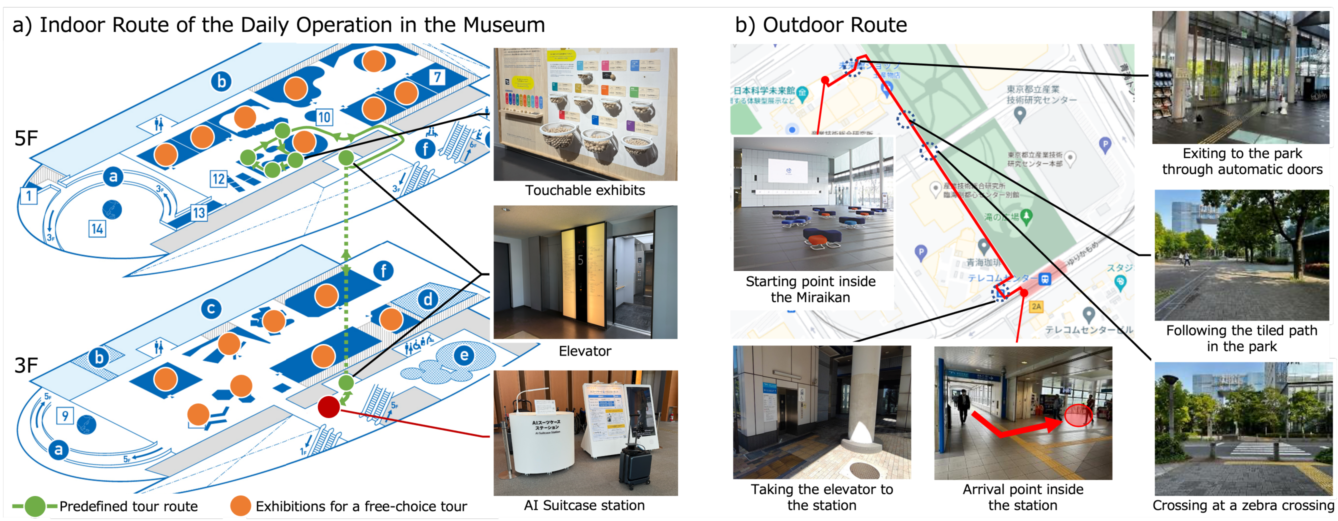

Figure 4: Route Maps for Trials at the Science Museum (Miraikan)

Table 1: Subjective Ratings for Daily Operation

	Q1: Overall Experience					Q2: Perception of Reliability and Safety in AI Suitcase Navigation					
	Very Dissatisfied	Dis-satisfied	Neutral	Satisfied	Very Satisfied	Very Unsafe and Anxious	Unsafe and Anxious	Neutral	Safe and Reliable	Very Safe and Reliable	Total
BVIs (total)	0 (0%)	4 (4%)	11 (12%)	32 (36%)	42 (47%)	0 (0%)	6 (7%)	19 (21%)	36 (40%)	28 (31%)	89
(age: ~20s)	0 (0%)	0 (0%)	2 (10%)	7 (33%)	12 (57%)	0 (0%)	0 (0%)	2 (10%)	10 (48%)	9 (43%)	21
(age: 30~50s)	0 (0%)	1 (3%)	3 (9%)	11 (31%)	20 (57%)	0 (0%)	4 (11%)	8 (23%)	15 (43%)	8 (23%)	35
(age: 60s~)	0 (0%)	3 (9%)	6 (18%)	14 (42%)	10 (30%)	0 (0%)	2 (6%)	9 (27%)	11 (33%)	11 (33%)	33
Sighted (total)	2 (1%)	1 (0%)	11 (5%)	77 (32%)	146 (62%)	0 (0%)	12 (5%)	38 (16%)	127 (54%)	60 (25%)	237
(age: ~20s)	1 (1%)	0 (0%)	3 (3%)	25 (23%)	79 (73%)	0 (0%)	3 (3%)	20 (19%)	52 (48%)	33 (31%)	108
(age: 30~50s)	1 (1%)	1 (1%)	7 (6%)	48 (42%)	58 (50%)	0 (0%)	7 (6%)	16 (14%)	69 (60%)	23 (20%)	115
(age: 60s~)	0 (0%)	0 (0%)	1 (7%)	4 (29%)	9 (64%)	0 (0%)	2 (14%)	2 (14%)	6 (43%)	4 (29%)	14

including total blindness or low vision. "Sighted" refers to all other respondents (including those who wear contact lenses or glasses).

For visually impaired participants, Q1 in Table 1 shows that 83% responded that they were "very satisfied" or "satisfied." Those who expressed satisfaction appreciated the freedom to choose exhibits and navigate independently. Many expressed their desire for AI Suitcase to be *"put to practical use as soon as possible."* Other comments were as follows: *"I was able to visit the exhibits in the order I wanted, at my own pace. When I go with friends, sometimes I have to compromise if they're not interested in the exhibits I want to see, but with the robot, I could spend as much time as I liked"* and *"It was good to have the next exhibit explained to me while moving because I could anticipate what was coming. I was able to walk while* *thinking more deeply."* Among the reasons for "dissatisfied" or "very dissatisfied" responses, those that could be addressed technically include *"I felt uneasy because no notification was given when the suitcase stopped."* In crowded situations, such as on weekends, the robot often stopped to avoid collisions with other pedestrians. This was a frequently mentioned concern, especially when the holdups occurred frequently.

Q2 in Table 1 shows that 71% of visually impaired participants responded that they felt "safe and secure" or "very safe and secure." On the other hand, the main reason for those who felt danger or anxiety was *"It stops in crowded places. There is a lot of acceleration and deceleration."* This opinion was also expressed by those who felt safe and secure. It is necessary to improve operation in crowded situations and ensure the ability to provide information when the robot stops.

For sighted participants, Q1 in Table 1 shows that 94% responded that they were "very satisfied" or "satisfied." They appreciated the freedom offered by AI Suitcase, similar to visually impaired participants. Additionally, they praised the system's convenience and ease of use. For Q2, 79% of sighted participants reported feeling "safe and secure" or "very safe and secure." Those who felt safe and secure provided comments such as *"The operation was simple"* and *"Even in crowds, it can stop or avoid people, so I was able to walk with peace of mind."*

3.3 Outdoor Testing

3.3.1 Overview. While it has become possible to operate the robot indoors on a daily basis, outdoor environments present greater challenges that have yet to be fully overcome. Outdoor surfaces are often uneven, and there are fewer walls available for LiDAR localization compared to indoor settings. To cross streets, the robot must navigate slopes and curbs that are not present indoors, and factors such as dust can also pose additional difficulties. Furthermore, the distance the robot needs to cover outdoors is likely to be significantly greater than in indoor environments.

Therefore, we developed an outdoor model of AI Suitcase with large wheels (Fig. 2) and tested the robot on the park path between the museum and the nearest train station in collaboration with the Tokyo Metropolitan Government and the railway company. We also consulted the local police department to ensure that the robot's operation complies with legal regulations. Due to its features—such as not functioning unless the user is holding the handle—the robot was classified as a "mobility aid," similar to an electric wheelchair. Obtaining such confirmation is especially important when conducting trials in outdoor environments.

The route was a 400-meter-long path with a zebra crossing at a two-lane road without a traffic signal (Fig. 4–b). The route in the first session in January 2023 was only outdoors, while the route in the second session in September included indoor-to-outdoor (museum to the park) and outdoor-to-elevator (park to the train station) transitions. Twenty BVI participants joined the January session, and fourteen joined the September session.

3.3.2 Results. We measured the System Usability Scale (SUS) [1] in the September session. The average score of 14 participants was 83.2, which can be interpreted as "acceptable" in acceptability, "B" in the grade scale, and "Excellent" in the adjective ratings. The lowest score was 64 and the highest was 100. We also asked about feelings of safety and comfortableness in stepping onto and off curbs, crossing streets at zebra crossings, getting in and out of elevators, and avoiding obstacles, pedestrians, and various objects. The worst scores involved negotiating curbs and zebra crossings (averages: 3.5 and 3.4).

Despite its large wheels (20 cm in diameter), the ability of the robot to overcome even a 3-cm curb rise was unstable, and it sometimes failed to surmount the curb, requiring the surrounding people to help the robot. If the robot speeds up to make the movement smoother, the shock when the robot reached the curb made the user uncomfortable. Through these experiments, we improved the algorithm and map to make the movement smoother during the trial period, but still the behavior was sometimes unstable. On the other hand, the basic obstacle and pedestrian avoidance system, as well as the vibration signal on the handle, worked well, similar to performance in the indoor environment, with an average score of 4.5 to 4.7.

4 Toward Practical Deployment

AI Suitcase received consistently high evaluations throughout these trials, with many participants expressing a desire for its commercialization. We also realized the need to overcome various challenges through the field trials. This section overviews these challenges and discusses future directions.

4.1 Cooperation with Facility Owners

Gaining the cooperation of all facility owners was crucial, regardless of the location. Setting up routes that posed no issues, contacting each tenant, and ensuring smooth execution were essential steps. In large areas, there were often multiple owners, and it was necessary to allocate sufficient preparation time to secure approvals from all of them. Additionally, for outdoor trials, it was necessary to obtain permissions from local governments and police. Since new mobility solutions for accessibility often fall into gray areas under existing laws, such efforts are unavoidable.

4.2 Crowded Situations

As experienced in the trials at the museum (Sec. 3.2.3), current robotics technology faces significant challenges in navigating reliably in environments crowded with pedestrians [12]. The basic strategy involves making safety-conscious temporary stops; however, these stops can impede traffic and cause anxiety among nearby pedestrians, as we experienced at the museum (Sec. 3.2.3). Francis et al. [4] classified the challenges of developing autonomous mobile robots in human-populated environments and proposed guidelines to evaluate social navigation. This direction will require extensive research and development activities, as well as data collection and trials on pedestrian movements in various real fields.

4.3 Real-world Information

The static information provided was insufficient for both the pilot study at the commercial complex and daily operation at the museum. Users expressed a desire for real-time updates about their surroundings. To bridge this disparity, future technological advances will be essential. For instance, innovative technologies like Vision Language Models [14] can be applied to interactively furnish crucial information to BVI users. These models can integrate data recognized by sensors and information sourced from the web, permitting a more comprehensive understanding of the surroundings.

4.4 Outdoor Navigation

As mentioned in Sec. 3.3.2, users have expressed concern about the robot's capability to navigate over curbs during outdoor operations. The current outdoor navigation model attempts to address this by equipping the robot with larger wheels (Fig. 2). Although we used wheels of about 20 cm in diameter, challenges still arose with the instability and impact experienced when crossing curbs that were only about 3 cm high. Furthermore, the outdoor environment presented unique challenges not typically found indoors, such as surfaces with different degrees of friction, tile edges, manholes, and iron meshes. Technical improvements are necessary to ensure stable navigation over such commonly found urban sidewalk obstacles.

4.5 Unobtrusive Freedom

BVI individuals inevitably stand out in public spaces because they need to carry a white cane or walk with a guide dog. This unavoidable visibility, with BVIs having no choice in the matter, was termed "loss of obscurity" by Thomas Carroll in his 1961 book [2], as one of the 20 losses experienced by visually impaired individuals alongside the loss of sight. This lack of choice in being conspicuous has long been recognized as an uncomfortable reality and a persistent challenge to BVI individuals. That is why one of the aims of the suitcase-shaped design is to allow users to navigate public spaces without standing out, offering a real choice for those who wish to blend in (Sec. 2).

However, a segment of the participants, especially those who joined the trial at a commercial complex (Sec. 3.1.2), expressed discomfort with being unobtrusive. They felt more comfortable and safer by standing out as blind persons using a white cane or guide dog to alert surrounding people to their presence.

This aligns with the principle espoused by Japanese traffic law, which mandates that a solo BVI person in public spaces use a white cane or a guide dog[3]. We encourage people to use a white cane even while employing the robot, in compliance with traffic laws. Particularly in Japan, the BVI community adheres to the common understanding that being visible in public spaces is essential. This requirement raises contradictory views within the community and thus necessitates discussion, not only among those in the BVI community but also with the general public and other stakeholders, such as organizations supporting the BVI and public agencies responsible for traffic safety.

For AI Suitcase, accommodating both perspectives is crucial. One idea is to attach a "sign" to the robot indicating that a blind person is walking with it. However, the true question we need to address is **"Should blind people be visible in public spaces to be safe, even with advanced robotics technology?"** With a navigation robot, the user can avoid obstacles and pedestrians and never miss the destination. While it is not impossible to imagine situations where the user and robot require support from surrounding people, such as getting stuck at a curb, these instances are dramatically rarer compared to using traditional navigation methods like white canes or guide dogs. We anticipate that as this new technology gains popularity and begins to earn the trust of the blind community, it will prompt changes in societal rules, including government regulations.

[3]Japanese Road Traffic Act, Article 14.1

4.6 Infrastructural Support

Elevators are a common feature in the urban environment, not just indoors but also as part of the transitional architecture from outdoor to indoor spaces, such as underground entrances. In fact, some of our trial routes involved elevators (e.g., Fig.4), and the robot was able to successfully navigate users into an elevator car and out again. However, it lacked the capability to call an elevator and select a destination floor. Users were asked to locate elevator buttons approximately 1.5 meters ahead and press the appropriate button for their intended direction, a task that proved to be challenging and occasionally necessitated assistance from experimenters. For real-world application, the robot should possess the ability to control elevators without requiring user intervention. In Japan, standards for indoor autonomous service robots to operate elevator cars are being discussed, and trials are already underway [16]. Implementing such infrastructure would significantly enhance the usability of the robot.

4.7 Limitations

This paper focuses on user experiences with a specific autonomous navigation robot, AI Suitcase, and thus its findings may not be directly applicable to other types of navigation robots. Most of our field experiments were conducted in Japan. We also carried out three field trials in the U.S.—at Carnegie Mellon University, Pittsburgh International Airport, and a hotel in Anaheim, California, during a conference. However, the number of participants was significantly larger in Japan.

5 Conclusion

This paper outlined the field trials of AI Suitcase, a navigation robot designed for the blind and visually impaired, and it scrutinized the hurdles facing its broad acceptance. It began by presenting the AI Suitcase concept and the basic technologies that drive the robot. Drawing from our three field trials, we discussed the challenges that come with introducing navigation robots to public spaces. The technical challenges also highlight potential areas of study for the research community, including enhancing real-world information processing, ensuring stable operation in crowded scenarios, and navigating through outdoor environments.

Our field trials garnered attention from many media channels, such as newspapers and popular television shows. The feedback from the blind and visually impaired community, along with that from the general public and policymakers, has been significantly positive. Encouraged by these outcomes, a larger field trial at the Osaka-Kansai Expo 2025 is planned. We hope that this paper will contribute to improving the social acceptance of robots and accelerate their social implementation.

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References

[1] John Brooke. 1995. SUS: A quick and dirty usability scale. *Usability Eval. Ind.* 189 (11 1995).

[2] T.J. Carroll. 1961. *Blindness: what it Is, what it Does, and how to Live with it.* Little, Brown, London, UK.

[3] National Library Service for the Blind and Library of Congress Print Disabled. [n. d.]. GPS and Wayfinding Apps. https://www.loc.gov/nls/services-and-resources/informational-publications/gps-and-wayfinding-apps/. Accessed: 2024-10-10.

[4] Anthony Francis, Claudia Pérez-D'arpino, Chengshu Li, Fei Xia, Alexandre Alahi, Rachid Alami, Aniket Bera, Abhijat Biswas, Joydeep Biswas, Rohan Chandra, Hao-Tien Lewis Chiang, Michael Everett, Sehoon Ha, Justin Hart, Jonathan P. How, Haresh Karnan, Tsang-Wei Edward Lee, Luis J. Manso, Reuth Mirksy, Sören Pirk, Phani Teja Singamaneni, Peter Stone, Ada V. Taylor, Peter Trautman, Nathan Tsoi, Marynel Vázquez, Xuesu Xiao, Peng Xu, Naoki Yokoyama, Alexander Toshev, and Roberto Martín-Martín. 2024. Principles and Guidelines for Evaluating Social Robot Navigation Algorithms. *ACM Trans. Hum.-Robot Interact.* (12 2024), 63 pages. https://doi.org/10.1145/3700599

[5] João Guerreiro, Daisuke Sato, Saki Asakawa, Huixu Dong, Kris M. Kitani, and Chieko Asakawa. 2019. CaBot: Designing and Evaluating an Autonomous Navigation Robot for Blind People. In *Proceedings of the 21st International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '19)*. ACM, New York, NY, USA, 68–82. https://doi.org/10.1145/3308561.3353771

[6] Bin Hong, Zhangxi Lin, Xin Chen, Jing Hou, Shunya Lv, and Zhendong Gao. 2022. Development and application of key technologies for Guide Dog Robot: A systematic literature review. *Robot. Auton. Syst.* 154 (8 2022), 16 pages. https://doi.org/10.1016/j.robot.2022.104104

[7] Brian F. G. Katz, Slim Kammoun, Gaëlle Parseihian, Olivier Gutierrez, Adrien Brilhault, Malika Auvray, Simon Thorpe, and Christophe Jouffrais. 2012. NAVIG: Augmented Reality Guidance System for the Visually Impaired: Combining Object Localization, GNSS, and Spatial Audio. *Virtual Reality* 16, 4 (2012), 253–269. https://doi.org/10.1007/s10055-012-0213-6

[8] Seita Kayukawa, Daisuke Sato, Masayuki Murata, Tatsuya Ishihara, Akihiro Kosugi, Hironobu Takagi, Shigeo Morishima, and Chieko Asakawa. 2022. How Users, Facility Managers, and Bystanders Perceive and Accept a Navigation Robot for Visually Impaired People in Public Buildings. In *2022 31st IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*. IEEE, New York, NY, USA, 546–553. https://doi.org/10.1109/RO-MAN53752.2022.9900717

[9] Seita Kayukawa, Daisuke Sato, Masayuki Murata, Tatsuya Ishihara, Hironobu Takagi, Shigeo Morishima, and Chieko Asakawa. 2023. Enhancing Blind Visitor's Autonomy in a Science Museum Using an Autonomous Navigation Robot. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23)*. ACM, New York, NY, USA, Article 541, 14 pages. https://doi.org/10.1145/3544548.3581220

[10] Izaz Khan, Shah Khusro, and Irfan Ullah. 2018. Technology-assisted white cane: evaluation and future directions. *PeerJ* 6 (2018), 27 pages. https://doi.org/10.7717/peerj.6058

[11] Masaki Kuribayashi, Tatsuya Ishihara, Daisuke Sato, Jayakorn Vongkulbhisal, Karnik Ram, Seita Kayukawa, Hironobu Takagi, Shigeo Morishima, and Chieko Asakawa. 2023. PathFinder: Designing a Map-less Navigation System for Blind People in Unfamiliar Buildings. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*. ACM, New York, NY, USA, 1–16. https://doi.org/10.1145/3544548.3581028

[12] Christoforos Mavrogiannis, Francesca Baldini, Allan Wang, Dapeng Zhao, Pete Trautman, Aaron Steinfeld, and Jean Oh. 2023. Core Challenges of Social Robot Navigation: A Survey. *ACM Trans. Hum.-Robot Interact.* 12, 3, Article 36 (4 2023), 39 pages. https://doi.org/10.1145/3583741

[13] Kakuya Naito, Reina Nakanishi, and Shunsuke Kimura. 2023. Verification experiment of autonomous mobile robot for mobility assistance of persons with visual disabilities: Needs survey for use in commercial facilities. *Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan (2023)* (9 2023), 1067–1068. (in Japanese).

[14] OpenAI. 2023. GPT-4 Technical Report. *arXiv preprint arXiv:2303.08774* (2023), 100 pages. https://arxiv.org/abs/2303.08774

[15] MIPsoft Oy. [n. d.]. BlindSquare. https://www.blindsquare.com/. Accessed: 2024-10-10.

[16] Robot Friendly Asset Promotion Association: RFA. [n. d.]. Robot Friendly Asset Promotion Association. https://robot-friendly.org/. Accessed: 2024-10-10. (in Japanese).

[17] Daisuke Sato, Uran Oh, João Guerreiro, Dragan Ahmetovic, Kakuya Naito, Hironobu Takagi, Kris M. Kitani, and Chieko Asakawa. 2019. NavCog3 in the Wild: Large-scale Blind Indoor Navigation Assistant with Semantic Features. *ACM Trans. Access. Comput.* 12, 3, Article 14 (Aug. 2019), 30 pages. https://doi.org/10.1145/3340319

[18] Susumu Tachi, Kazuo Tanie, Kiyoshi Komoriya, and Minoru Abe. 1985. Electrocutaneous Communication in a Guide Dog Robot (MELDOG). *IEEE Transactions on Biomedical Engineering* BME-32, 7 (1985), 461–469. https://doi.org/10.1109/TBME.1985.325561

[19] Kazuteru Tobita, Katsuyuki Sagayama, Mayuko Mori, and Ayako Tabuchi. 2018. Structure and Examination of the Guidance Robot LIGHBOT for Visually Impaired and Elderly People. *Journal of Robotics and Mechatronics* 30, 1 (2018), 86–92. https://doi.org/10.20965/jrm.2018.p0086

[20] Carnegie Mellon University. [n. d.]. CaBot - Indoor navigation for the visually impaired. https://mrsdprojects.ri.cmu.edu/2017teamg/. Accessed: 2025-1-7.

[21] WeWALK. [n. d.]. WeWALK. https://wewalk.io/en/. Accessed: 2024-10-10.

[22] Anxing Xiao, Wenzhe Tong, Lizhi Yang, Jun Zeng, Zhongyu Li, and Koushil Sreenath. 2021. Robotic Guide Dog: Leading a Human with Leash-Guided Hybrid Physical Interaction. In *2021 IEEE International Conference on Robotics and Automation (ICRA)*. IEEE, New York, NY, USA, 11470–11476. https://doi.org/10.1109/ICRA48506.2021.9561786

[23] Jing Yang, Amit Barde, and Mark Billinghurst. 2022. Audio augmented reality: A systematic review of technologies, applications, and future research directions. *Journal of the Audio Engineering Society* 70 (10 2022), 788–809. Issue 10.