

Orinav: An Accessible Navigation Smartphone App for People with Visual Impairments

Second Stage R&D Proposal

1. Background

Safe and independent travel for people with visual impairments remains a pressing need and is an essential part of building a modern, accessible society. According to data from the National Bureau of Statistics, there were 85.91 million people with disabilities in China at the end of 2023, including 28.57 million with visual impairments, and about 450,000 new cases each year. A 2016 survey by the China Information Accessibility Product Alliance found that among 1,805 respondents with visual impairments, about 30% seldom left home, and only 9% went out four to six times per week or more without a family member. In daily life, people with visual impairments often face two challenges: an “information gap” (difficulty obtaining important information about the surrounding environment) and “spatial disorientation” (difficulty maintaining orientation and planning the next step in complex and dynamic road environments).

With national governance and digital infrastructure continuing to develop, accessible travel is receiving increasing policy attention. The Law on the Construction of Accessible Environments, implemented in September 2023, incorporates accessible environment construction into a specialized legislation and highlights the need to include information accessibility and social services alongside physical infrastructure. The law directs governments at all levels to provide safe and convenient travel and information services for persons with disabilities and encourages the R&D, production, application and promotion of assistive technologies, products and services through funding and other measures. In October 2025, national planning documents for the 15th Five-Year Plan for economic and social development urged improvements to barrier-free public facilities and services for persons with disabilities. These developments show a growing emphasis on raising awareness of accessibility concepts and promoting related technologies.

Even with increasing policy support, people with visual impairments still face a range of difficulties when traveling. A field survey by Chongqing University on the travel environment of people with visual impairments in China pointed out many issues they face in daily travel, including safety hazards caused by facilities such as overpass ramps, the risk of collisions from common obstacles on sidewalks, and temporary environmental changes such as construction areas increasing the difficulty of finding one’s way. To address this, various sectors of society have begun actively exploring solutions. For example, new regulations in Hunan and other places include information accessibility in the construction

of a digital society and explicitly require travel software such as map navigation to improve barrier-free markers and route planning. Since its launch in 2022, Amap's accessibility navigation feature has provided more than 150 million accessible route plans, and in August 2024 it upgraded by adding "navigation for people with visual impairments," offering tactile-paving-based route planning and traffic light recognition, among other features. However, due to limitations in data accuracy, the traffic light recognition and tactile paving navigation functions have limited coverage.

For people with visual impairments, successful navigation requires the answer to three key questions: "Where am I?", "Where am I going?" and "How do I get there?" Yet existing navigation solutions often do not respond adequately to these questions or are not user-friendly for people with visual impairments. Taking "How do I get there?" as an example, this question actually contains two levels: macro-navigation, which is determining the overall route to the destination, and micro-navigation, which is determining each step to take during the actual walk. Most existing navigation applications only focus on macro-navigation and lack solutions that integrate micro-navigation. Although accessibility navigation functions in common navigation software implement some micro-navigation functions, due to the limited data on traffic lights and tactile paving, many scenarios remain uncovered. To solve this problem, we have developed Orinav. Orinav combines map data with image data captured by the phone's camera to integrate outdoor macro- and micro-navigation, with the goal of helping people with visual impairments achieve "door-to-door" navigation.

2. Related Works

Existing research has formed a relatively rich technical foundation in the field of navigation for people with visual impairments, but overall has not yet achieved true "door-to-door" navigation. These solutions can be roughly divided into two categories: market products already in practical use and research systems in the literature. The former proves that related functions are feasible in practice, while the latter further show that current systems often cover only part of the navigation chain: some focus on route planning, others on local environment perception, and a few hybrid systems involve both but often rely on extra equipment or infrastructure. Ultimately, these systems find it difficult to support "door-to-door" navigation for people with visual impairments in real environments.

2.1. Related Products in the Market

Among market products, Amap is one of the most representative cases in China. Amap's accessibility navigation was launched in 2022, initially mainly serving wheelchair users. In August 2024, its accessibility navigation further added "navigation for people with visual impairments," which can prioritize routes containing tactile paving and provide voice reminders of traffic lights and off-route correction prompts when passing through intersections. Public reports show that as of November 2024, Amap's accessibility navigation had provided more than 150 million accessible route plans. Amap's strength lies in integrating accessibility capabilities into existing navigation ecosystems by relying on mature map data and a mainstream travel platform; however, its traffic light voice reminder function, which is very important, covers only a small range due to data gaps. At the same

time, Amap has not yet fully leveraged the rich entrance data it has, so users with visual impairments still cannot use it to complete “door-to-door” navigation.

Google Maps represents the mainstream map product internationally. In its walking navigation, Google Maps introduced a “detailed voice guidance” feature that allows more frequent announcements of whether you are on the correct route, how far to the next turn and whether you are approaching a large intersection. Meanwhile, Google Maps has accumulated accessible facility information for more than 50 million places, which users with visual impairments can refer to. Google Maps excels at global route guidance, but its capability can still only bring users near the destination and cannot yet help users with visual impairments perceive the environment, so it still cannot constitute complete “door-to-door” navigation on its own.

Besides mainstream software, more specialized products aimed at users with visual impairments have also appeared. For example, the Chinese-developed Shike Navigation provides functions such as destination search, surrounding broadcasts, road angle tips and navigation to favorite locations, which are closer to the daily use scenarios of users with visual impairments. However, from the product capability perspective, Shike Navigation still mainly focuses on direction prompts and location broadcasts, and its support for intersection prompts, destination entrance prompts and traffic light prompts is still limited, so it cannot yet serve as a complete navigation software.

Internationally, many navigation apps developed for people with visual impairments need to be used with other navigation software. Microsoft’s Soundscape continuously broadcasts roads, intersections, landmarks and points of interest through 3D audio, helping users form a spatial understanding of their surroundings. It is generally run in the background while other navigation software runs in the foreground. BlindSquare is also a widely used accessible navigation app that can continuously broadcast the current location, nearby intersections, points of interest and the direction to the destination, and it can be used in conjunction with third-party navigation applications. Such products are very valuable in enhancing the spatial understanding of users with visual impairments, but because they have not integrated more complete traffic light recognition, route planning and other functions, users rely more on complete barrier-free infrastructure. In areas lacking such infrastructure, users cannot achieve “door-to-door” navigation.

Overall, market products have already covered multiple aspects such as route planning, location broadcasting, surrounding environment hints and tactile-paving-priority routing, but most have not integrated these functions. Mainstream map products focus more on route planning, while apps such as Soundscape and BlindSquare emphasize environmental perception. Because existing products have not fully bridged various navigation tasks, users still find it difficult to rely solely on a single system to achieve “door-to-door” navigation.

2.2. Related Research in the Literature

Relevant research in the literature shows a similar distinction. Since there are already many macro navigation systems in the market, macro navigation systems in the literature are mainly designed for other specific scenarios. For example, the SUBE system uses Bluetooth beacons to help users get on and off buses, and the system proposed by Velázquez et al. uses tactile insoles to feed back the current position. These studies are effective in specific

scenarios but often rely on additional equipment and thus have high promotion costs. Other micro navigation systems in the literature specifically solve environmental recognition. The CyARM system proposed by Ito et al. uses ultrasound and tactile feedback to help users avoid obstacles; the system proposed by Schwarze et al. uses stereoscopic vision and spatial audio to prompt obstacle positions but requires a head-mounted camera and backpack-style equipment; Peng et al. proposed an early mobile phone obstacle detection application that can remind users of risks ahead in real time but requires the phone to maintain a fixed posture, which is not natural to use. Subsequently, Huang et al., Bhowmick et al. and Hoang et al. respectively used Microsoft Kinect technology, wearable hardware or tongue electrical stimulation to perform obstacle recognition or feedback. More recently, DeepNAVI has been able to run entirely on a smartphone and integrates multiple functions such as scene recognition in addition to obstacle recognition. Even so, these systems generally do not have route planning capabilities, limiting their usability in outdoor navigation.

Existing literature has also attempted to propose systems that combine micro navigation and macro navigation. For example, Tyflos combines stereoscopic vision and laser scanning for scene description and navigation; Drishti combines outdoor GPS with indoor ultrasonic positioning to achieve voice navigation; TARSIUS combines a mobile app with Bluetooth beacons that provide environmental information. The latest navigation system ENVISION has already moved onto phones, combining GPS navigation with obstacle recognition within the same mobile app, representing progress compared with the aforementioned solutions that rely on additional facilities. However, these systems still have certain limitations: Tyflos, Drishti and TARSIUS all require extra facilities, and although ENVISION runs on a phone, its functions focus on obstacle recognition and cannot yet handle key situations such as crossing roads. In other words, hybrid systems show that combining macro navigation and micro navigation is the right direction, but they have not yet truly completed coverage of the entire travel cycle “door-to-door.”

Therefore, whether looking at market products or research systems in the literature, they all point to the same conclusion: most existing solutions can only solve part of the problems in navigation for people with visual impairments and cannot fully answer the three questions: “Where am I?” “Where am I going?” and “How can I get there safely?” Compared with existing systems, the ultimate goal of the Orinav project is to integrate macro navigation and micro navigation into one continuous system on a smartphone as much as possible to cover the complete outdoor travel process from starting point to destination, thus moving toward “door-to-door” navigation.

3. First Stage R&D Results

3.1. Software Development

The long-term goal of the Orinav project is to provide people with visual impairments with complete “door-to-door” navigation support, that is, to solve key problems such as route planning, direction judgement, obstacle avoidance and crossing intersections throughout the entire outdoor travel process from starting point to destination. Existing solutions often cover only part of this: some only provide turn-by-turn navigation; others only provide local environment perception, making it difficult to truly support people with visual impairments

to complete continuous, independent real travel. In the first stage of R&D, Orinav initially connected these links on the phone, forming a basically usable integrated navigation prototype.

In the first stage, the project first built the core functional framework, forming a complete system that includes navigation, environment perception and information output at the same time. The system runs on the iOS platform and integrates macro navigation, micro navigation and output modules, enabling it to provide a variety of accessibility functions within the same application and convey information to users via voice and tactile feedback. The system architecture is shown in Figure 3-1.

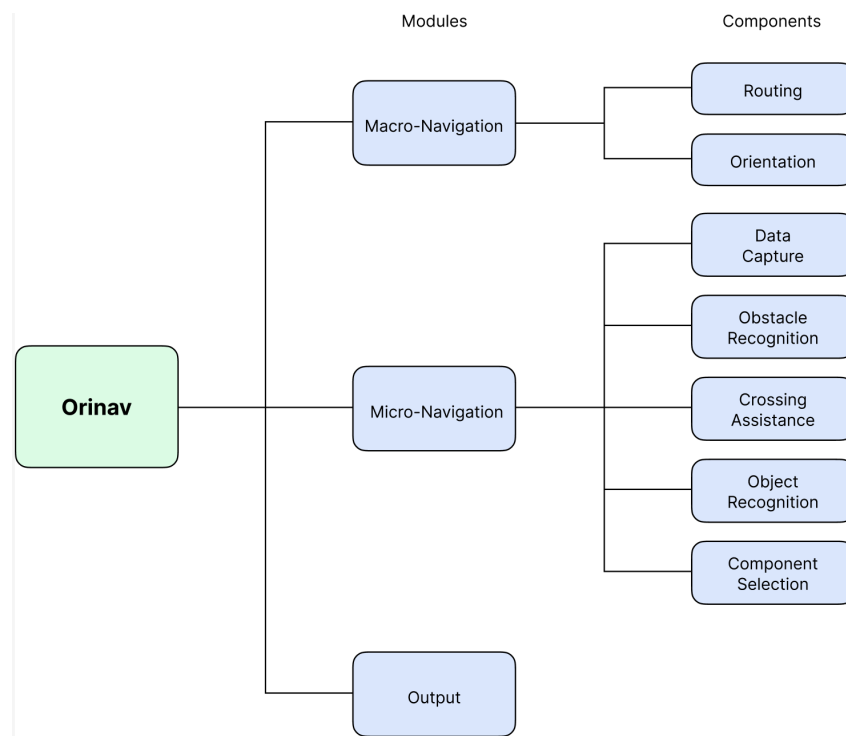


Figure 3-1. Orinav’s modular design.

From a functional perspective, the Orinav prototype implemented in the first stage has initially covered several key links in “door-to-door” navigation.

In terms of route planning, Orinav can already provide destination search, route selection and step-by-step navigation and adapts to use scenarios for people with visual impairments. The system provides more frequent voice prompts during navigation and allows users to replay current instructions on demand. At the same time, the traditional interactive map interface is hidden by default to reduce the operational difficulty in screen reader environments, and users can also obtain information about nearby locations via voice while walking. Secondly, in the first stage Orinav implemented continuous orientation on sidewalk direction. The system helps users judge whether they have deviated from the correct direction during walking. Orinav adopts a clock-direction expression method more suitable for people with visual impairments—for example, prompting users to adjust direction with “facing 1 o’clock” or “facing 3 o’clock.” Overall, the first stage has achieved

accessibility modification of traditional route planning functions, enabling users not only to know the destination but also to follow route progress more clearly.

In terms of environment perception, Orinav implemented multiple functions oriented to real road scenes: obstacle recognition, crossing assistance and object recognition. Obstacle recognition uses camera and depth sensor data to remind users of potential risks ahead while walking. Crossing assistance is divided into crosswalk recognition using open map data, which actively reminds users when they approach a crosswalk, and traffic light recognition using camera data, which can inform users of the status of traffic lights and the waiting time required. For people with visual impairments, crossing streets is one of the highest-risk and decision-intensive scenarios in the entire travel process. Orinav automatically activates the traffic light recognition function when it detects a crossing scenario and provides reminders as the user approaches the road. Before and after crossing, the orientation function helps users face the correct direction. Object recognition can broadcast the names of common objects around to help users better understand the current environment. By providing environmental support during walking, Orinav has started to have the continuous assistance capabilities necessary for “door-to-door” navigation.

3.2. User Testing

To evaluate Orinav’s effect on the key elements of “door-to-door” navigation—safety, efficiency and usability—in real situations, we recruited 18 people with visual impairments adults for testing. Participants completed three similar outdoor routes of about 200 meters each, with each route corresponding to one navigation condition: using Orinav with a white cane, using Amap’s accessibility mode with a white cane and using only a white cane. The experimental routes all included one turn and one traffic-light intersection that had not undergone accessible renovation, reflecting two types of decision points for people with visual impairments in real outdoor scenarios.

As shown in Figure 3-2, the first-stage Orinav prototype showed certain advantages in efficiency, safety and usability. In terms of completion time, the average completion time when using Orinav was 297.48 seconds, shorter than 339.34 seconds under the Amap condition and 367.64 seconds under the cane-only condition, with statistically significant effect. Secondly, in terms of hesitation counts, Orinav averaged 3.72 hesitations, lower than 6.67 for Amap and 6.11 for cane only, indicating that users were more certain at critical nodes and the walking process was smoother. At the same time, in terms of approaching dangerous areas, Orinav averaged 1.22 times, significantly lower than 2.17 for Amap and 2.28 for cane only, indicating some improvement in safety. Finally, for subjective usability, the System Usability Scale (SUS) score for Orinav averaged 85.00 (out of 100), indicating that participants generally found Orinav easier to understand and use. These results together show that the first-stage Orinav prototype can already provide a more efficient, safer and more user-friendly experience for people with visual impairments in real travel to some extent.

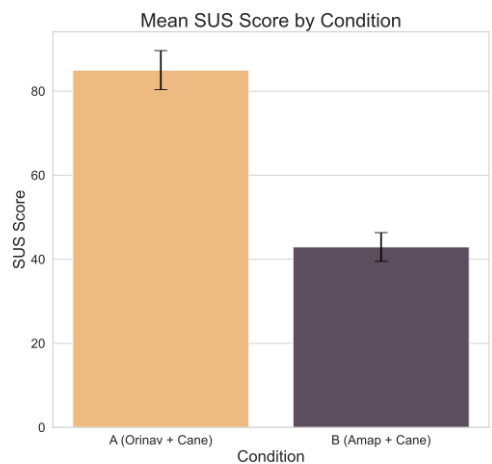
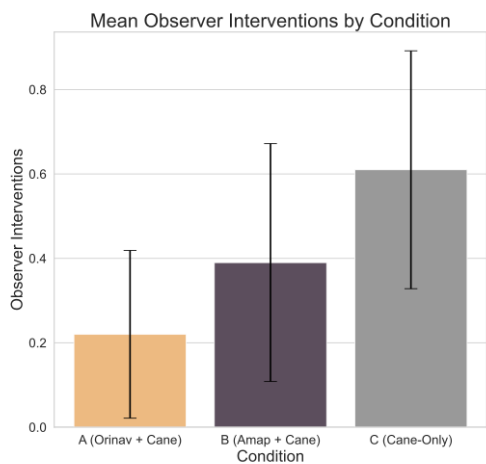
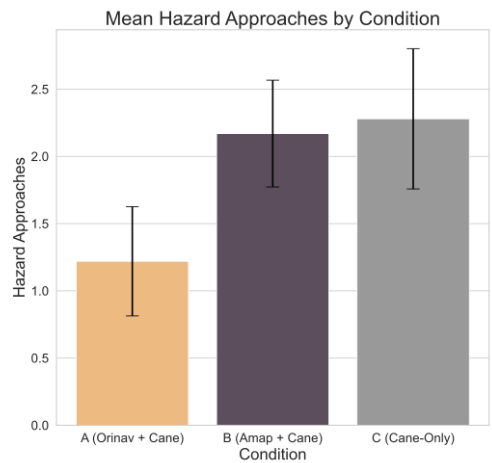
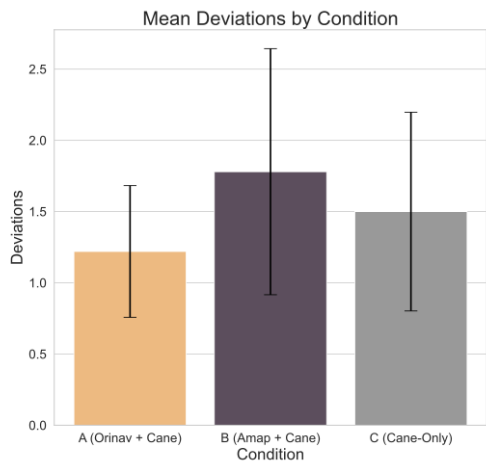
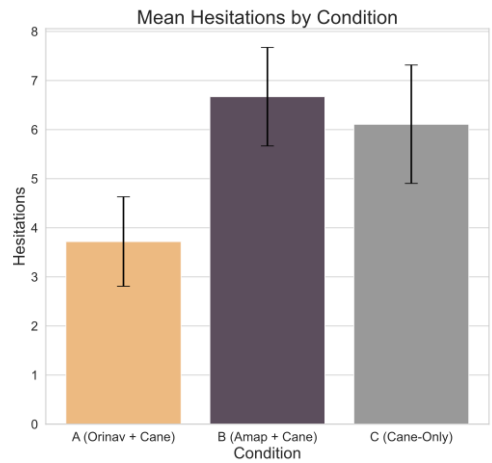
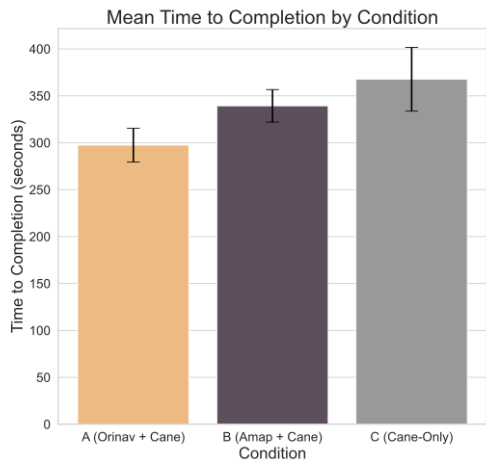


Figure 3-2. Testing results under three experimental conditions: A (Orinav + cane), B (Amap + cane), and C (cane only). Error bars indicate 95% confidence intervals. n = 18. Except for SUS score, lower is better.

In addition to quantitative data, open-ended feedback after the experiment also showed that the first-stage functions brought some practical value to users. A qualitative analysis of the open-ended questionnaire after the tasks showed that participants generally believed that Orinav’s interface was clearer, more screen-reader-friendly and that the automatic switching functions reduced cognitive load. They said that the crossing recognition and obstacle recognition functions enhanced their confidence when traveling. At the same time, users proposed many directions worth further improvement in the next stage, including expanding the range of traffic light recognition, adding tactile paving recognition, further optimizing obstacle prompts and implementing entrance navigation. This shows that although the first-stage design is effective, it still falls short of complete “door-to-door” navigation.

3.3. Summary

Overall, the first-stage R&D has resulted in the following phased achievements:

1. Orinav has initially integrated macro navigation and micro navigation on the mobile phone.
2. The system has implemented key functions such as route guidance, direction alignment, obstacle recognition, crossing assistance, traffic light recognition and object recognition.
3. These functions have shown improvements in efficiency, safety and usability in real user experiments.
4. User feedback shows that these functions indeed increase travel confidence and initially realize the “door-to-door” outdoor navigation that people with visual impairments need.

Since September 2025, the Orinav test version has been exhibited in multiple venues. In September 2025, Orinav was exhibited to the Beijing public at the “Youth and Accessible Environment Construction” themed exhibition hosted by the Institute for Accessibility Development at Tsinghua University. In November 2025, Orinav was selected to be exhibited at the “Inclusive Innovation” industry event held by assistive technology company Envision Technologies. The audience on-site included more than 100 users, industry practitioners and researchers. We collected valuable feedback from local users about privacy protection, local infrastructure, etc. at the event, and established cooperative relationships with companies in the industry such as Envision and Sensotec. Related video clips of the event have been viewed more than 2,000 times on online platforms. In December, Orinav was presented as a student project at the “Building the Future Ideal School” international seminar at Beijing Middle School before more than 800 experts from various fields, and it was reported by News Express and The Beijing News. Recently, the iOS public beta version of Orinav has officially been launched on the App Store and obtained 334 users from five countries worldwide in the first two months of public testing.

Although the first stage has initially integrated some important navigation functions into a mobile app, the prototype still has some distance from complete “door-to-door” navigation. In terms of functionality, the current obstacle recognition lacks more precise direction and distance expressions—users know there is a risk ahead but cannot always quickly judge the exact direction and remaining distance of the obstacle; the traffic light-related functions still

need to add automatic orientation capabilities towards traffic lights to reduce the burden on users to find the recognition angle at intersections; in addition, tactile paving recognition and entrance navigation functions have not been added, leaving specific tasks in navigation without full support; finally, the Orinav software can only run on the iOS platform and lacks support for the Android system, which is commonly used by people with visual impairments. Therefore, we plan to carry out the second-stage R&D of Orinav with the goal of basically achieving “door-to-door” navigation through Orinav.

4. Second Stage R&D Plan

4.1. Overview

The overall goal of the second-stage R&D of the Orinav project is to further fill the key links that have not yet been completed based on the first-stage prototype system, improve the usability of the software in real road environments and realize “door-to-door” navigation.

The proposed period for the second-stage study is from April 2026 to September 2026, for a total of six months. This stage of work will focus on two key tasks: continuing to advance software function development and conducting user testing in real scenarios aimed at product optimization, continuously improving the navigation experience based on the test results.

4.2. Software Development

Second-stage software development mainly includes two aspects: expanding the software platform and adding key functions.

First, we plan to complete the development of the Orinav Android version by April 2026. Currently, Orinav only supports the iOS platform, whereas a considerable portion of people with visual impairments in China use Android phones. This platform limitation restricts the coverage of test subjects and is not conducive to subsequent promotion. After the development of the Android version is completed, Orinav will be able to conduct testing and optimization for a broader range of users with visual impairments, laying the foundation for practical application.

Second, we plan to concentrate on developing the following three key functions from May to June 2026:

- **Tactile paving recognition.** In the first stage, users were already able to obtain route guidance, crossing assistance and obstacle prompts, but according to user feedback, the software could not directly identify tactile paving, which affected users who needed to use tactile paving. In the second stage we plan to add a tactile paving recognition function, enabling the software to judge whether the user is near tactile paving and the approximate direction of its extension in real road environments, helping users judge the location of the tactile paving. Adding this function will help solve the problem that narrow and shallow tactile paving is prone to deviation and improve the user’s travel experience.

- More precise crossing assistance. The first stage already achieved a certain degree of crossing support, but the accuracy of guidance on the direction of traffic lights and intersections is still insufficient. The second stage plans to focus on enhancing crossing assistance so that the software can more accurately determine the start and end of each intersection and more accurately guide users to face the correct direction of the traffic lights. This function is related to the actual effect of the software in high-risk intersections and is one of the most important links in realizing “door-to-door” navigation.
- Entrance recognition. Existing navigation products generally can bring users near the destination but find it difficult to solve how to reach the specific entrance in the last tens of meters. In the second stage, we plan to add an entrance recognition function, enabling the software to more accurately identify the entrance of buildings, locations or communities and provide precise prompts for the last segment when users approach the destination. This function will play a decisive role in achieving entrance-level navigation for true “door-to-door” navigation.

To complete the above software development tasks, the project team will need support in two aspects during the second stage.

- Technical support. The second stage will involve the development of new functions such as tactile paving image recognition and entrance recognition. These functions pose technical challenges in machine learning, user feedback and routing algorithms, so it is necessary to connect with software engineers or technical teams with relevant experience to obtain technical assistance in image recognition and feedback implementation.
- Data support. Second-stage software development will require more refined spatial data support, including information such as building entrances, site entrances, intersection and traffic light positions, and the start and end of zebra crossings. Public map data currently available is not fine-grained enough to support high-precision navigation for people with visual impairments, whereas map providers such as Tencent Maps and Amap have collected this kind of fine data in product development but have not made it public. Therefore, we need to strive to obtain higher-precision spatial data from relevant map providers in the second stage to improve the technical feasibility of the new functions.

4.3. Software Testing

After completing the above development, software testing will be conducted in August to September 2026 in the second stage. The test location is planned to be the Dongba area of Chaoyang District, Beijing, and 50 people with visual impairments test users are planned to be invited to participate.

The testing work will mainly be aimed at product optimization. By having users use the software on real routes, we will observe its actual performance, collect specific problems and improvement suggestions and further optimize the software’s functions and interaction methods based on them. The test route is planned to be unified as the route from the Beigangzi Bus Stop to the South Gate of Baxin Jiayuan. A unified test route ensures similar

usage scenarios, making it easier to compare problems encountered by different users. The route also has a certain representativeness, covering several key scenarios commonly encountered by people with visual impairments during real walking, such as sidewalk travel, turning, crossing, tactile paving interruptions and approaching entrances.

During the implementation of the test, participating users will use Orinav to complete the above route. Users can raise opinions or point out problems during the walk, and volunteers will be arranged on site to observe and record. After the test, feedback will be collected from the participants to understand their overall evaluation of the navigation experience.

To complete the second-stage testing work, assistance from the Dongba Township government is required to help contact local people with visual impairments test users. Because the current team's direct channels to people with visual impairments community are limited, leveraging the power of local government will help cover a wider range of people with visual impairments of different ages, travel habits and needs, making the test results more representative.

References

China Information Accessibility Product Alliance. (2016). *Report on the Basic Situation of Internet Users with Visual Impairments in China*. https://capa.run/static/image/img_media/中国互联网视障用户基本情况报告.pdf

Bhowmick, A., Prakash, S., Bhagat, R., Prasad, V., & Hazarika, S. M. (2014). IntelliNavi: Navigation for Blind Based on Kinect and Machine Learning. In *Multi-disciplinary Trends in Artificial Intelligence* (pp. 172–183). Springer International Publishing. https://doi.org/10.1007/978-3-319-13365-2_16

Bourbakis, N.G., & Kavraki, D. (2001). An intelligent assistant for navigation of people with visual impairments. In *Proceedings of the 2nd Annual IEEE International Symposium on Bioinformatics and Bioengineering (BIBE 2001)* (pp. 230–235). IEEE. <https://doi.org/10.1109/BIBE.2001.974434>

Hoang, V.-N., Nguyen, T.-H., Le, T.-L., Tran, T.-T. H., Vuong, T.-P., & Vuillerme, N. (2015). Obstacle detection and warning for people with visual impairments based on electrode matrix and mobile Kinect. In *2015 2nd National Foundation for Science and Technology Development Conference on Information and Computer Science (NICS)* (pp. 54–59). IEEE. <https://doi.org/10.1109/NICS.2015.7302222>

Huang, H.-C., Hsieh, C.-T., & Yeh, C.-H. (2015). An Indoor Obstacle Detection System Using Depth Information and Region Growth. *Sensors*, 15(10), 27116–27141. <https://doi.org/10.3390/s151027116>

Ito, K., Okamoto, M., Akita, J., Ono, T., Gyobu, I., Takagi, T., Hoshi, T., & Mishima, Y. (2005). CyARM: an alternative aid device for blind persons. In *CHI '05 Extended Abstracts on Human Factors in Computing Systems* (pp. 1483–1488). ACM. <https://doi.org/10.1145/1056808.1056947>

Khenkar, S., Alsulaiman, H., Ismail, S., Fair, A., Jarraya, S. K., & Ben-Abdallah, H. (2016). ENVISION: Assisted Navigation of people with visual impairments Smartphone Users. *Procedia Computer Science*, 100, 128–135. <https://doi.org/10.1016/j.procs.2016.09.132>

Kuriakose, B., Shrestha, R., & Sandnes, F. E. (2023). DeepNAVI: A deep learning based smartphone navigation assistant for people with visual impairments. *Expert Systems with Applications*, 212, 118720. <https://doi.org/10.1016/j.eswa.2022.118720>

Martinez-Cruz, S., Morales-Hernandez, L. A., Perez-Soto, G. I., Benitez-Rangel, J. P., & Camarillo-Gomez, K. A. (2021). An Outdoor Navigation Assistance System for people with visual impairments in Public Transportation. *IEEE Access*, 9, 130767–130777. <https://ieeexplore.ieee.org/document/9534900/>

Mataro, T. V., Masulli, F., Rovetta, S., Cabri, A., Traverso, C., Capris, E., & Torretta, S. (2017). An assistive mobile system supporting blind and people with visual impairments when they are outdoors. In *Proceedings of the 2017 IEEE 3rd International Forum on Research and Technologies for Society and Industry (RTSI)* (pp. 1–6). IEEE. <https://doi.org/10.1109/RTSI.2017.8065886>

National Bureau of Statistics, People's Republic of China. (2023). National Data. Retrieved March 13, 2026, from <https://data.stats.gov.cn>

Peng, E., Pursue, P., Li, L., & Venkatesh, S. (2010). A Smartphone-Based Obstacle Sensor for people with visual impairments. *Ubiquitous Intelligence and Computing*, 6406, 590–604. https://doi.org/10.1007/978-3-642-16355-5_45

Ran, L., Helal, S., & Moore, S. (2004). Drishti: an integrated indoor/outdoor blind navigation system and service. In **Proceedings of the Second IEEE Annual Conference on Pervasive Computing and Communications** (pp. 23–30). IEEE. <https://doi.org/10.1109/PERCOM.2004.1276842>

Schwarze, T., Lauer, M., Schwaab, M., Romanovas, M., Böhm, S., & Jürgensohn, T. (2016). A Camera-Based Mobility Aid for people with visual impairments. **KI – Künstliche Intelligenz**, 30(1), 29–36. <https://doi.org/10.1007/s13218-015-0407-7>

Velázquez, R., Pissaloux, E., Rodrigo, P., Carrasco, M., Giannoccaro, N., & Lay-Ekuakille, A. (2018). An Outdoor Navigation System for Blind Pedestrians Using GPS and Tactile-Foot Feedback. **Applied Sciences**, 8(4), 578. <https://doi.org/10.3390/app8040578>

Wang, C., Zhou, Y., Liao, Y., & Chen, Y. (2025). Current Status and Optimization Strategies of Accessible Environments for people with visual impairments in China. **Journal of Chinese Urban Forestry**, 23(5), 46–54. <https://doi.org/10.12169/zgcsly.2025.09.15.0003>