Mobile Applications for Assisting Mobility for the Visually Impaired Using IoT Infrastructure

Jee-Eun Kim[1], Masahiro Bessho[1], Noboru Koshizuka[1,2] and Ken Sakamura[1,2]
[1]Interfaculty Initiative in Information Studies, The University of Tokyo.
[2]YRP Ubiquitous Networking Laboratory.
{kim, besshy, koshizuka, ken}@sakamura-lab.org

***Abstract*—Visually impaired people (VI) face many challenges while travelling. Despite many research efforts in this area, no single solution has yet been widely accepted by the blind community, mainly because existing systems cannot satisfy all of VI's mobility needs, and usually require additional dedicated hardware that is expensive and cumbersome. In our ongoing research to facilitate off-the-shelf smartphones that are useful travel aids and support a wide range of mobility challenges, in this paper, we propose three location-based services (LBS) that can be used from smartphones without requiring additional hardware. We demonstrate how Internet of Things (IoT) infrastructure for positioning, and web APIs for retrieving relevant information based on user's context can facilitate independent travel for VI. The evaluation of each LBS indicates that the proper use of IoT technology can support VI mobility effectively.**

Keywords—Internet of Thing; accessibility; visual impairment; location-based services; smartphone

I. Introduction

One of most challenging issues faced by the visually impaired is the achievement of independent mobility, because it mostly depends on visual cues—traffic lights, road signs, landmarks, obstacles on sidewalks, etc. The inability or the decreased ability to go out alone imposes significant difficulties in their daily lives—getting to school, work, health care, shopping, and other facilities. According to the World Health Organization, as of 2014, an estimated 285 million people are visually impaired worldwide [1]. Visual impairment cost Japan an estimated $72.8 billion dollars in 2007 [2], indicating that vision loss and blindness have a considerable impact on society.

Recently, much research effort has been made to improve the travel experiences of blind people, taking advantage of wireless communication networks (e.g., RFID, Wi-Fi, Bluetooth, 3G) and the smartphone sensing capabilities equipped with GPS, camera, compass, accelerometer, etc. However, they mostly require additional hardware; for example, Braille keyboards [3], vibrotactile motors attached to a smartphone [4], vibrotactile bracelet [5], ect., or physical augmentation of the environment, which is costly and cumbersome. Consequently, a white cane remains the primary travel aid, and few or no systems have yet been widely accepted for the blind and visually impaired community [6].

Our ultimate research goal is to enhance the mobility of visually impaired people in a wider range of travel activities—getting knowledge of surrounding points-of-interest (POI), using public transportation, navigation, etc.—by utilizing off-the-shelf mobile devices without requiring additional dedicated hardware or expensive equipments such as a Braille keyboard. Because it is clearly beneficial to have one device that supports all travel activities [7], modern smartphones have a great potential to become useful mobility aids for VI.

To facilitate the use of smartphones as effective travel aids for VI across all possible mobility challenges, we believe that the Internet of Things (IoT) infrastructure and APIs that retrieve data efficiently of "things" from the Internet should be provided, so that cost-effective LBS can be developed, allowing VI to immediately and continuously access the information needed while traveling. However, it is not clear how and to what extent current mobile technology can be used to improve the mobility of VI. In this paper, we demonstrate the value of IoT infrastructure and web APIs for effective smartphone-based travel aids by developing three different LBS for VI and presenting how they can be used in VI's mobility scenarios.

The rest of this paper is organized as follows. Section II introduces the IoT infrastructure we have proposed. In Section III, we present three LBS in detail. Section IV discusses the three LBS with respect to IoT technology's impact on mobility aids, and the potential for assisting further travel activities using IoT. Finally, Section V concludes this paper.

II. IoT Infrastructure

This work is a part of our ongoing comprehensive study that has been conducted over a decade on IoT technologies including real-time embedded operating systems [8], wireless sensor networks, ubiquitous identification (uID) technology [9], and security for ubiquitous computing [10]. In particular, ubiquitous ID architecture, a distributed information service architecture that allows the retrieval of relevant information from physical objects and places is our fundamental idea for realizing an IoT environment. In this architecture, unique identifiers (*ucode*) are assigned to "things" and places. *ucode* is a 128-bit number and can be stored into any type of tag medium such as RFID, QR-code, NFC and Bluetooth Low Energy (BLE). A distributed database server, called a *ucode* resolution server, manages the corresponding relationship

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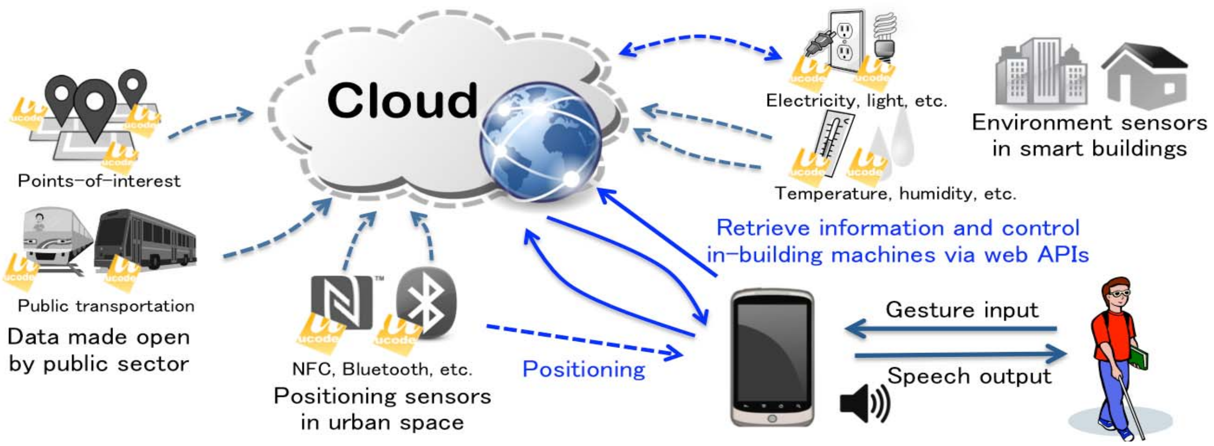


Fig. 1. IoT infrastructure based on ubiquitous ID architecture.

between ucodes and the servers that provide content related to the ucodes.

As shown in Fig. 1, based on the uID architecture, we have been building IoT infrastructure that densely deploy sensors in urban spaces both for location-awareness (RFID, NFC, BLE, etc.) and environment sensing (light, temperature, humidity, etc.). The position sensors are installed both indoors and outdoors, so that seamless positioning can be achieved along with GPS, Wi-Fi, and cellular networks. Our IoT infrastructure manages every "things" uniquely by ucodes, and provides APIs that access information of "things" (timetables of nearby buses) and control "things" (elevators, air conditioners). These APIs are available over the Internet, and allow applications to easily access and control "things" in the cloud. Based on this concept, the APIs available on the IoT infrastructure include:

- *Kokosil API* [11] provides access to local businesses and facilities information in Ginza, a famous shopping and entertainment district in Tokyo.
- *OpenData API* [12] provides real-time access to massive public transit information in the Tokyo metropolitan area.
- *Smart Building API* provides real-time access to the environmental information (e.g., temperature, humidity, etc.) of a smart building, and provides control over in-building machines such as elevators and air conditioners.

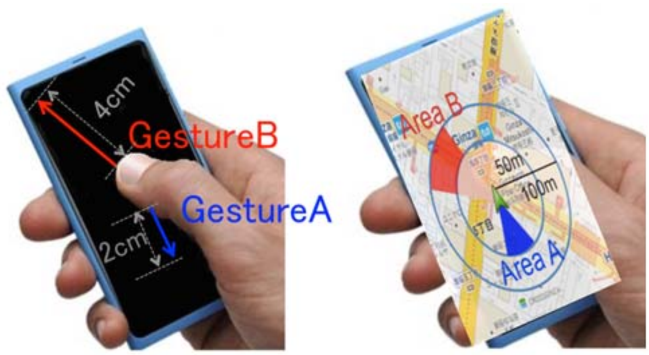
III. Location-based services for the visually impaired

We have developed three location-aware systems running on smartphones taking advantage of infrastructure presented in Section II: SaSYS [13], TalkingTransit [14] and Smart Building Application. SaSYS and TalkingTransit have been iteratively co-designed and developed with blind users. The task-based user studies in [13] and [14] showed that blind people were able to use SaSYS and TalkingTransit, and the interaction designs of both systems were generally well accepted. The Smart Building Application is a prototype system on which we are currently working. In this section, we briefly summarize each LBS focusing on the functionality and the use of IoT infrastructure prior to discussing the potential of smartphones and IoT infrastructure for addressing the needs of blind travelers.

A. SaSYS

Swipe and Scan Your Surroundings (SaSYS) is a location-aware system that allows VI to search for surrounding POIs such as local businesses and facilities. SaSYS aims to support VI's information needs for surrounding environments when walking around a town or spending time in a place with no specific destination, making their exploratory travels more independent and enjoyable. In order to develop useful and easy-to-use POI search systems, we recognized the following important requirements.

- Spatial interaction techniques should be provided to allow VI to interact effectively with geo-located information space, so that users are able to discover POIs in areas-of-interest both intuitively and simply.
- Fine-grained control over Text-to-Speech (TTS) should be provided to allow VI to effectively navigate audio information and find the information they want to find.



Swiped distance	Corresponding search area
0-3 cm (Gesture A)	within 50m radius (Area A)
Over 3 cm (Gesture B)	50m-100m radius (Area B)

Fig. 2. Example of "Swipe-to-search". Gesture A and Gesture B retrieve POIs in Area A and Area B, respectively.

Fig. 3. VI users performing TTS controls: (A) Skip by drawing a triangle and (B) Forward by drawing a greater-than sign.

SaSYS has been implemented on the Android platform, and currently run on the Samsung Galaxy S2 and the Galaxy Nexus. Leveraging smartphone's GPS and compass functions, SaSYS provides the following functionalities:

- *"Swipe-to-search*." Users can easily search for POIs using simple swipe gestures that allow VI to specify where to search intuitively. Swipe gestures indicate the direction (relative to the direction they are facing) and distance of areas-of-interest (See Fig. 2). For example, a short left-swipe finds nearby POIs on the left and a long right-swipe finds distant POIs on the right.

- *TTS controls*. Users can choose what to listen to from audio information by making the TTS skip, repeat, go forward or backward, and increase or decrease the speech rate using gestural commands—drawing simple shapes on the touch screen—as shown in Fig. 3. This feature could help VI "look over" or "look into" POI information.

SaSYS takes advantage of the Kokosil API to retrieve POI information in Ginza. Fig. 4 illustrates the software architecture of SaSYS. First, "Gesture Detector" detects a gesture performed by a user. Then, "Search Manager" determines a target area to search. After that, "Contents Manager" retrieves POIs from Kokosil API. Then, "TTS Player" sends a proper sentence to the TTS engine according to the gestural commands. HTTP requests with parameters such as GPS coordinates, search range, and sorting options for

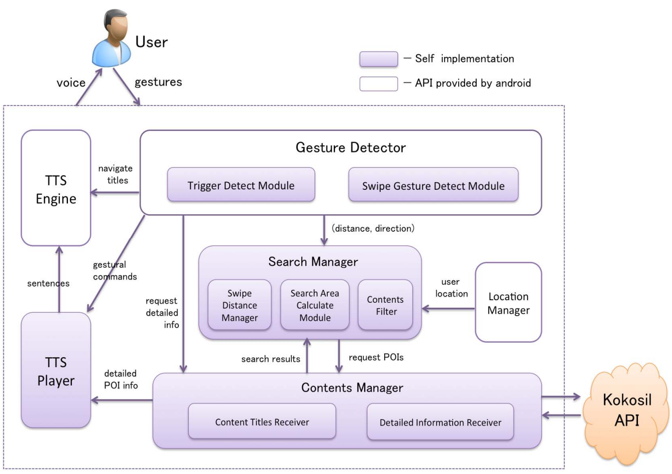


Fig. 4. SaSYS software architecture.

Fig. 5. VI user obtaining arrival time for the next bus using TT

results return a JSON response. The Kokosil API provides rich information about POI. For example, a store's information includes general information such as the store name, business hours and address, *ucodes* related to the store, geometry (GPS and multi-polygon coordinates), and links to other social network services that can provide further information about the store.

B. *TalkingTransit*

By collaborating with Japanese railway and bus operators, we developed TalkingTransit (TT) to improve public transit accessibility for VI in the Tokyo metropolitan area. Tokyo's public transportation system is one of the most complex systems in the world. For example, Shinjuku station, which is considered as the world's busiest station with 30 platforms and 66 exits. Finding your way around such a busy station is difficult even for sighted people, let alone the visually impaired. To make transportation facilities more accessible for VI, we co-designed TT with blind users with the following four functionalities:

- *Timetable search*. Users can get the arrival times for the next vehicle (See Fig. 5), and a full timetable by using one of the two search modes, according to their usage scenarios. *GPS-based search* allows users to search for the timetables of trains/buses within 500 m of their current position, which can be useful when they are going to nearby stations or already at bus stops. Meanwhile, *alphabetical search* allows users to find the timetables of trains/buses by a specific station name, which can be helpful when they plan a journey.

- *Checking the real-time service status of railways*. Users can obtain real-time updates on delays, service changes and suspensions for railway agencies in Tokyo, which allows them to deal with unexpected situations that involve service changes.

- *Bookmarks*. Users can get easy access to timetables for the vehicles that they use frequently by bookmarking pairs of stations and train lines, and stations and bus routes.

- *Automatic notification of in-station information*. Users can be notified when they are within 2 m of points of reference for a nearby platform, and facilities such as stairs, escalators, and toilets. If users receive a notification of a nearby platform, they can directly access

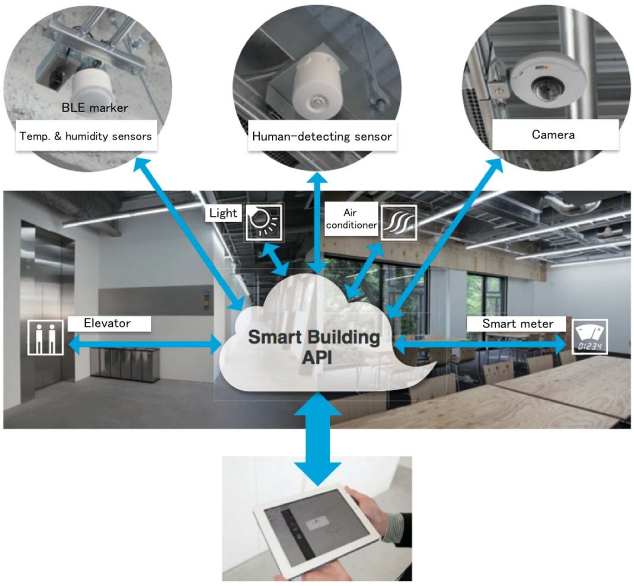


Fig. 6. Smart applications using Smart Building API

to the timetables of the trains that will arrive at that platform.

TT is developed integrating the concepts of IoT and Open Data infrastructure. In-station information is provided by utilizing infrastructure that densely deploy BLE markers in railway stations. BLE, which has an approximately 1-2 meter range, is an especially useful technology for VI, because the user can receive information about his vicinity without user interaction such as touching the marker [15]. Furthermore, BLE technology can be used by readily available smartphones, suggesting its impact on improving mobility of VI.

Thanks to the OpenData API, efficient and cost-effective application development can be made with well-designed HTTP interfaces that retrieve massive public transit information, made open by 11 railway operators, including East Japan Railway and private railways; two subway operators (75 lines and 1270 stations in total) and Toei Bus (132 routes and 1585 stops). Without the OpenData API, developers would have to cope with retrieving data from each transit agency, which returns different JSON data, causing repetitive code for parsing each agency's data format. Some transit agencies may not even provide web APIs. In such cases, developers may need to parse the HTML of a transit agency's website to get data, which can decrease development efficiency.

C. *Smart Building Application*

Unlike the aforementioned two applications that are tailored for VI through an iterative design process with blind users, this application is currently in the first stage of development process.

Currently we are prototyping smart applications using IoT technologies at the Daiwa Ubiquitous Computing Research (DUCR) Building which is a state-of-the-art smart building in

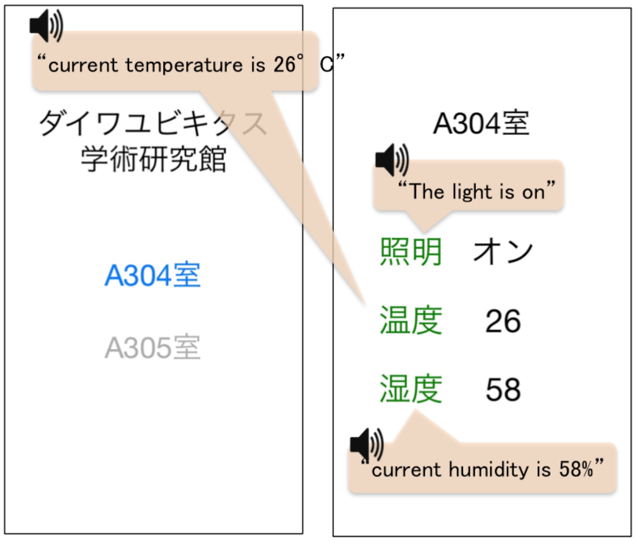


Fig. 7. Example screens of smart building application.

the University of Tokyo. Using Smart Building APIs, in-building machines such as elevators and air conditioners can be operated and managed based on real-time environmental contexts, such as the current user's location, temperature, humidity, and electricity usage which are collected by various sensors (temperature, humidity and human-detection), BLE markers, and cameras that are deployed throughout the building (Fig. 6). To make the DUCR Building more accessible, we are currently developing a prototype for possible usage scenarios to identify VI's needs.

At present, we are considering the following use cases for smart applications for VI. The application should be able to identify different rooms in the building and notify that along with contextual information of the rooms (e.g., temperature, humidity, light/air conditioner operating status, etc.) to the user. Upon entering a room that the VI rarely uses, they may wish to know about the interior layout, such as the location of the control panel, switchboard, etc.

The current version of the smart building application provides the following functionality for VI:

- *Room status monitoring*. Users can check the status of the light (on/off), current room temperature, and humidity. This information will be provided audibly, upon swiping the screen as shown in Fig. 7.
- *Air conditioner and light controls*. Users can turn air conditioners and lights in a room on and off by double tapping the screen.
- *Automatic notification of in-building information*. Users will be given an audio notification when they are within 2 m of the BLE markers that are installed in front of each door. For example, if the user comes within the BLE signal range of room A304, the application will read aloud, "You are in front of A304, the student room."

IV. DISCUSSION

This research project was motivated by the strong need for exploring and learning about one's environment. Since many research efforts in this area have been made in providing turn-by-turn directions to a predetermined destination, existing guidance systems are insufficient to meet that need. Therefore, in this research project, we have mainly focused on enhancing the ability to obtain the information needed while traveling.

Before discussing the travel aids for blind people, it is important to understand different types of activities for independent mobility. Mobility has been defined by Foulke [16] as "the ability to travel safely, comfortably, gracefully, and independently". In Brambring's model [17], the mobility of VI involves two types of activities: Perception of objects and process of orientation. Mobility also can be interpreted as an activity that includes a set of capabilities—space perception, orientation, wayfinding, navigation, and obstacle avoidance [6]. Meanwhile, the travel activity can be interpreted as a wider concept that encompasses not only mobility but also environmental access which involves issues related to the ability to obtain information needed while traveling; for example, access to street signs, information about location, public transport information, and etc. [7]. Although there are slight differences between the classification models, they are basically similar. Thus, for discussion, we classified the tasks involved in the travel activity into two categories: Environmental access and mobility. Tasks related to environmental access include access to points of interest, public transport, buildings, electronic kiosks, and street signs. Tasks related to mobility include space perception, navigation & orientation, and obstacle avoidance. Based on this classification, the following sections present how the three location-based services we developed can support travel tasks and discuss the potential of current IoT infrastructure for further travel aids.

A. Support for environmental access

1) Points of interest, public transport, and buildings. SaSYS helps VI access to information about locations *in situ* by utilizing APIs for local searches and simple swipe gestures on a smartphone. Although knowledge of the surrounding facilities, shops, and restaurants may not be essential when moving between places, it is crucial for independent and enjoyable traveling. TalkingTransit helps VI access public transit information using APIs for data made open by public sector. The system also allows VI to simply walk along a concourse and receive relevant information seamlessly, taking advantage of BLE markers installed in train stations. The Smart Building Application was developed for VI to support their daily lives in a smart building. Like TalkingTransit, the application allows VI to obtain location information such as a room number seamlessly *in situ* using BLE markers and APIs. Utilizing such smart APIs, VI can both access in-building information and control air conditioners and lights in rooms.

Regarding SaSYS and TalkingTransit, we demonstrated that both applications could enhance environmental accessibility through user studies with blind users. Regarding the Smart Building Application, it would be usable for VI in respect of its user interface, the design of which is based on simple touch gestures that were well accepted by VI with TalkingTransit. Future work should investigate into the effectiveness of functionality by conducting a user study in a smart building.

2) Electronic kiosks. It could be possible for VI to access and use electronic kiosks such as ATMs and vending machines in public spaces with BLE markers and web APIs to obtain the information of the machines and control them. For example, when a blind person gets close to a vending machine with a BLE marker, a mobile application could notify him of the machine's presence and read aloud the goods available. If the vending machine supports online payment and provides API for payment, he can easily buy goods without having to find the slot and insert the right coins or bills. This approach can be of benefit for everyone. For example, people in wheelchairs—who may have difficulty with pushing out-of-reach buttons on vending machines—can buy goods easily.

3) Street signs. By attaching BLE markers to street signs and graphics, VI can also access to information presented to them through smartphones, even though it may not be a practical solution. To help VI access to visual or textual information, computer vision-based approaches have been proposed to detect texts in urban spaces [18]. A crowdsourcing-based approach can be a possible solution. For example, using a mobile application such as VizWiz [19], VI can ask questions about street signs by taking pictures and receive answers back quickly from sighted people on the web.

B. Support for mobility

1) Space perception. Regarding space perception, we believe that SaSYS's swipe-to-search interface has great potential to support space perception for VI by letting them know about the high-level spatial relationship between the locations of surrounding objects. This potential has been identified by the user study where we asked blind participants to find given POIs and to represent their spatial relations on a LEGO board by fixing their current position for experimental purpose. From the user study results, we identified that they generally understood spatial relationships among POIs. However, the current version of the GPS-based SaSYS is insufficient in that its position accuracy of within approximately 15 meters is not acceptable for VI to understand the spatial relationship. If the current BLE-based positioning infrastructure is extended to wider areas, including both indoors and outdoors areas, SaSYS could improve the high-level spatial awareness of VI in the field.

2) Navigation & orientation. So far, our research efforts have been made to enhance environmental access, although we have recognized that BLE markers that provide precise location information have a great potential to be used for navigation systems for blind people, especially in indoor spaces. Future work includes developing a smartphone-based navigation system that can take advantage of BLE-based positioning.

3) Obstacle avoidance. The current IoT infrastructure and smartphone technology may not be suitable for obstacle avoidance because installing BLE markers into every possible obstacle and managing them would be inefficient. Possible solutions have been proposed to help VI detect and avoid obstacles. For example, EyeCane [20] estimates a distance to an obstacle by using a beam of light, and allows blind users to learn the distance via tactile and auditory cues.

To summarize, with the current IoT infrastructure and smartphone technology, accessibility for VI to the environment—points of interest, public transport, buildings, and electronic kiosks—can be improved. For the accessibility of street signs and graphics, technically it could be supported by BLE marker installation, but other approaches such as computer vision-based text detection and crowdsourcing-based question answering systems can be more effective solutions. For the tasks related to mobility, the ability to navigation & orientation can be improved with BLE-based positioning; and by integrating SaSYS's spatial interaction technique, the ability to space perception also can be enhanced. However, supporting obstacle avoidance with the current IoT infrastructure and smartphones would be challenging.

Through experience of developing LBS with blind people, we have identified that by utilizing smartphone's built-in sensors and customized gestures, mobile applications can be made highly accessible. Furthermore, thanks to built-in screen readers in smartphones, the usage of smartphones is increasing among the blind community [21]. Thus, we believe that our approach of using a smartphone as a system component is promising. In addition, it is important to let developers recognize that there are many blind users who own a smartphones and use them as much as the general population [21], to encourage the development of accessible mobile applications. This can bring many choices for LBS with different interfaces, so that they can choose one according to their preference.

V. Conclusion

In this paper, we have introduced three applications, called SaSYS, TalkingTransit and Smart Building Application, which can be used by readily available smartphones without any specialized hardeware. These applications show how IoT infrastructure and APIs that are available over the Internet benefit blind and visually impaired people by facilitating cost-effective and useful location-based services. Currently, we are planning the real-world future deployment of SaSYS and Talking Transit. We are also planning to conduct longitudinal studies for these two applications so that we could analyze the travel strategies used by blind individuals and could identify potential needs.

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