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A Public Transit Assistant for Blind Passengers: Development and Experiments

German H. Flores and Roberto Manduchi

Abstract—Public transit is key to independence for many blind persons. Unfortunately, in spite of recent accessibility progress, use of public transportation remains challenging without sight. In this contribution, we describe the development of and experiments with a system that provides enhanced travel-related information access to a blind bus passenger. Users of this system can select a specific bus line and desired destination on a regular Android smartphone or tablet; they are notified when the bus arrives; once in the bus, they are informed of its progress during the route; and they are given ample advance notice when the bus is approaching their destination. This system was tested with four blind participants in realistic conditions. These experiments were followed by interviews, with questions ranging over the participants' experience with public transit systems, and their impressions of the proposed system.

Index Terms—Public transit, independent travel, visual impairment.

I. INTRODUCTION

Public transit has a critical role in the independence of blind travelers [14]. Blind persons who use public transportation have more opportunities for employment, education, leisure, and socialization. Yet, blind travelers face difficulties with the use of public transportation [22][19][1], despite accessibility advances promoted by the American with Disability Act (ADA) or similar legislation. In particular, access to travel-related information, which contributes to the travelers' comfort and safety, may be difficult for those who cannot see. A passenger needs to ascertain which train or bus line to take, when the vehicle departs, and where the vehicle should be boarded. While riding, passengers need to be made aware of the progress made to destination, allowing them to prepare to exit the train car or bus vehicle when it arrives at the desired stop. Non-visual (acoustic) modalities can be used to facilitate some of these tasks. For instance, the ADA prescribes that bus vehicles announce stops at major destinations, major intersections, transfer points, stops requested by riders with disability, and in general frequently enough to allow visually impaired passengers to orient themselves [9]. In practice, stops are sometimes not announced or announced only at the last

second. Some passengers, particularly those with some hearing impairments, may find it difficult to hear the acoustic announcements produced by the speakers, especially when there is loud noise from the environment. Individuals who are unsure, anxious, or have a certain amount of cognitive impairment, may benefit from hearing the same announcement repeated multiple times [1].

This paper describes a qualitative study with a system (Public Transportation Assistant, or PTA) specifically designed to support blind travelers riding a bus vehicle, and in particular to increase information awareness for these passengers. Our system uses WiFi Access Points (AP), which are placed inside bus vehicles as well as at bus stops. These APs communicate with the user's Android smartphone or tablet. Our system requires no Internet connection and doesn't need to use the GPS in the user's phone/tablet. Passengers who are within the WiFi range of an AP placed at a bus stop receive information about the bus lines transiting through that stop, their timetables, and possibly other types of location-based information. While inside a bus, passengers may receive information from the AP located in the vehicle about the current progress through the route. This system allows for pre-selection, using a specially designed accessible interface, of the desired bus line and destination stop. Passengers waiting at a bus stop receive a notification when the desired bus is approaching; once inside the bus, passengers are notified with good advance time when the bus is about to reach the desired stop. Information is produced as synthesized speech. Users can always request the system to repeat its last announcement, and interrogate it to obtain other available information.

Our PTA system was tested with four blind participants. The participants operated the PTA while riding a bus along a specific route in the UC Santa Cruz (UCSC) campus. Participants employed the PTA system in a very realistic scenario. Their task included riding two different AP-equipped busses, after selecting specific destinations, and exiting each bus at the designated stop. They also participated in a semi-structured interview after the experiment. In this interview, they shared their experience with the public transportation system, discussed all perceived accessibility issues, and provided feedback about the PTA system just tested. These experiments and interviews highlight some of the problems faced by blind individuals while using public transportation, and provide a critical assessment of the functionalities of our PTA device.

II. RELATED WORK

Several researchers have addressed the problem of providing information access to travelers with cognitive or

sensorial impairments [1]. For example, Azenkot et al. [2][15] studied the use of Braille notetakers to enable access to arrival times (as generated by OneBusAway [10]) for blind and deaf-blind travelers. Access to location-contingent data in General Transit Feed Specification (GTFS) format was implemented in the ABLE Transit system [17], with the user’s location estimated via GPS. Likewise, Ubibus [4] was a proposal to enhance existing services by ubiquitous computing with the goal to facilitate transit information access by a blind person. The Accessible Bus System [20] used Bluetooth beacons to inform the user when a desired bus has arrived. Bluetooth beacons have also been used in the URNA project to provide blind users with information about the status of a traffic light at an intersection [5]. Other projects have considered the needs of travelers with cognitive impairments [11][8][21]. For example, the Travel Assistance Device [3] used the traveler’s GPS to determine the location of the bus he or she is riding, and to inform the traveler when the bus is approaching a desired stop (a similar system was described in [24]). Differently from the work cited above, our PTA system was designed from the ground up with the goal to support passengers throughout the whole travel, from the moment they arrive in the vicinity of the first bus stop, to the time they reach their destination bus stop.

Besides accessing trip-related information, passengers with visual impairment often have difficulties recognizing a bus stop, or orienting themselves in a transit hub. Standard mapping services (e.g. Google Maps) and accessible GPS apps (e.g. BlindSquare or Sendero’s Seeing Eyes GPS) can be used for this purpose, but they have critical shortcomings. For example, Google Maps only provides the location of bus stops, but not their layout descriptions. Also, the relatively low spatial accuracy of GPS (10 meters or more) does not allow blind users to, for example, determine whether they are at the desired bus stop, or at a bus stop across the street. The StopFinder project [7][23] created a database of detailed descriptions of layouts of bus stops, collected via crowdsourcing. Guentert [15] described an iPhone app designed to allow a blind person explore the layout of a train station. Hara et al. [16] presented a system that uses crowdsourcing to build a database of bus stop locations that includes layout descriptions. As highlighted in the interviews with our participants, this type of spatial information can be very useful for blind passengers.

Preliminary results with our PTA systems were presented in [12][13].

III. PTA TECHNICAL DESCRIPTION

A. Client/server Architecture

Our PTA system uses WiFi Access Points (APs), deployed at bus stops and inside transit vehicles. Each AP is essentially a router that acts as a server, and communicates information with a client application running on an Android device. This application manages connections, communication and overall user interaction.

APs can be of two types: *in-vehicle APs* and *bus stop APs*.

APs store local databases containing the information that needs to be communicated at each connection request. In-vehicle APs communicate with an optional GPS device for positioning.

We designed an Android app that was implemented in a Nexus 7 tablet for our experiments. This app incorporated the following functionalities: WiFi connectivity requests, touch gesture interactions, local database queries, and text-to-speech synthesis. WiFi connectivity requests include connecting, disconnecting and switching between in-vehicle and bus stop APs; touch gesture interactions include detecting multi-touch gestures from the user such as single tap, press-and-hold, and swipe; database queries include accessing a local database to extract relevant bus time schedule information and a list of instructions and confirmations; and text-to-speech synthesis is in charge of converting written instructions, confirmations, and any other information from the database into speech.

During operation, the smartphone application first scans for available networks, to verify whether they are within the effective or the actual range. The *effective range* is defined as the maximum distance (~70 m) at which the client application detects that an AP is within vicinity, but may not be able to communicate. The *actual range* is the distance (~55 m) at which an AP is detected and able to communicate with the client application. When the client is within the actual range of an AP, it sends a connection request and waits for an acknowledgement from the AP. If acknowledged, the connection remains opened and data is sent from the AP to the client.

B. User Interface/Application Scenarios

The goal of our system’s user interface is to communicate relevant information to users in accessible form, and to provide them with the proper set of instructions and

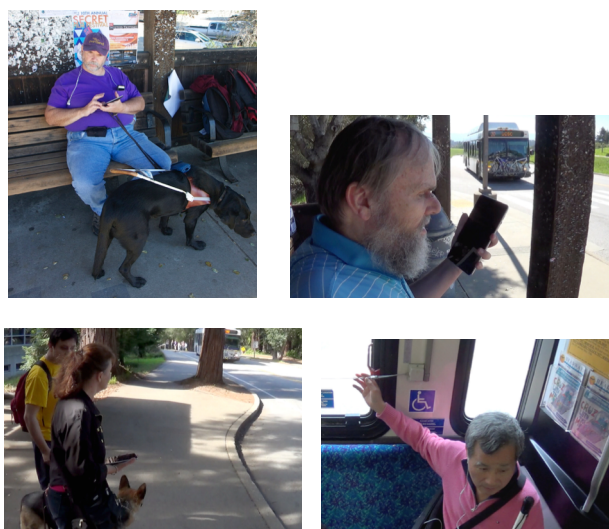


Fig. 1. Blind participants during our user studies. In clockwise order starting from top left: interacting with the application on the tablet; being informed by the system that the 20 bus has arrived; pulling the cord to call the stop; waiting to hear from the system whether the arriving bus is the desired one.

confirmations for specifying the desired task. This interface is based on multi-touch gesture interactions and text-to-speech synthesis.

The following describes a typical scenario of application of our PTA system. A blind person walks to a bus stop and starts the PTA app on his or her smartphone. Upon notification by the app that a bus stop AP is within range, the user interacts with the system to select the bus line of interest, as well as the destination stop. If two (or possibly more) APs are within range (a situation that may occur, for example, in the case of two bus stops facing each other across the street), the user is asked to select the desired AP. More specifically, the app lists all APs within range (with their names, e.g. “Science Hill – East” and “Science Hill – West”) as menu items, and prompts the user to select one.

After this initial system interaction, the user is instructed to wait for the desired bus to arrive. The user can at any time interrogate the system, requesting to hear the remaining estimated time till bus arrival. As soon as the desired bus arrives and is within range of the user phone’s WiFi, connection is automatically switched to the in-vehicle AP placed in the bus, and the user is informed that the desired bus has arrived. The user is then expected to enter the bus and find a seat. The in-vehicle AP, which is now connected to the client application, updates the app about the current bus location, and about upcoming stops being approached by the vehicle. At any time, the user can review the last information produced by the application, and can request to have this information repeated multiple times if desired. A special notification is produced once the vehicle approaches the stop located before the desired one. This feature was introduced to ensure that the user would have enough time for things such as pulling the cord to call the stop, standing up and moving towards the door, etc. Upon arrival at the final stop, the system prompts the user to exit the bus. After the user has left the vehicle and the bus has departed, the app disconnects from the in-vehicle AP and enters idle mode.

IV. EXPERIMENT DESIGN

A. Participants

We recruited four blind participants for our experiment. In order to preserve their anonymity, participants are assigned fictional names in this paper: Albert, Bill, Candace, and Donald (see Fig. 1). A short description of each participant, along with his or her general travel habits, is provided below.

Albert is a 55 years old man, who is blind except for some residual light perception in one eye, and has regular hearing. He has outstanding mobility skills, and normally walks with his dog guide. He is an experienced iPhone user; in fact, he regularly tests new assistive technology devices and apps. He is very familiar with the local bus system and uses public transportation on a regular basis (although he prefers to walk to places when they are not too far away). In a typical week, Albert completes 4-5 round trips by bus.

Bill is a 58 years old blind man with no residual sight and good hearing. He uses a long cane for mobility. Bill is

technologically savvy and likes to try new accessible apps on his iPhone. He likes walking to places if his destination is within a couple of miles and it is not raining, otherwise he takes the bus (on average, 3-4 times per week). He never takes Paratransit.

Candace is a 64 years old woman who has been blind for most of her life, with only some light perception left, and no hearing problems. She uses a dog guide when she moves around. She does not own a smartphone and is generally not too interested in technology. Candace doesn’t often go to unfamiliar places at this point in her life, although she did in the past. She used to take public transportation; now she prefers to take taxicabs and, occasionally, Paratransit. She currently uses public transportation only 2-3 times a year..

Donald is a 67 years old man who lost his sight as a teenager due to a traumatic brain injury. He has some level of hearing impairment, especially in his left ear. He is fairly proficient with technology, and loves his iPhone. Donald is highly mobile and used to travel around the world for business. He uses a long cane as a mobility device. In recent years, he has only used private transportation (or took public transportation but accompanied by his wife). During his college years (in Japan), Donald would take the bus every day to school and, occasionally, to locations he was unfamiliar with, for example to visit a friend.

B. Installation

Three bus stops in our University campus and one bus vehicle were instrumented with APs. Fig. 2 shows the locations of the bus stops in the campus where APs were placed. Specifically, we instrumented two bus stops (“Science Hill – East” and “Science Hill – West”) facing each other in the upper part of campus, as well as one bus stop (“East Remote Parking – West”) in the lower part of campus (see Fig. 3). The reason for instrumenting two bus stops facing each other is that a user located at one bus stop would be in



Fig. 2. Top: Science Hill – East (left) and Science Hill – West (right) bus stops. Bottom: East Remote Parking – West bus stop.

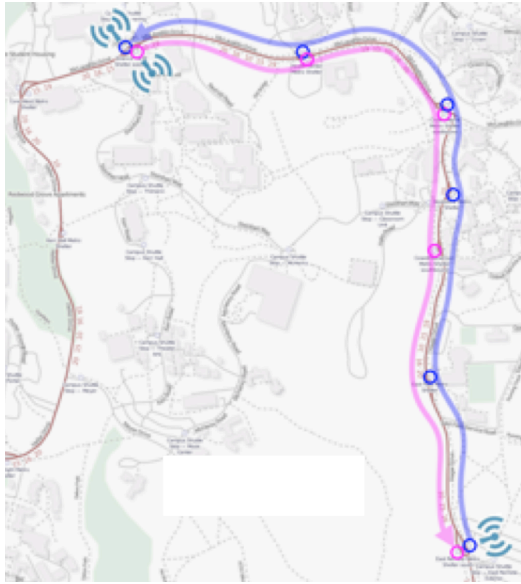


Fig. 3. Campus map with bus routes used in our experiments. The eastward and westward routes are shown by thick lines, colored in pink and light blue, respectively. The bus stops traversed by the routes are shown by colored circles. The bus stops with WiFi Access Points are marked with a characteristic symbol.

the WiFi range of both APs, and we wanted to test how easy it would be for the user to select the correct AP and remain connected to it.

C. Procedure

We conducted individual user studies during February and March of 2015. We purposely decided not to perform a “dry run” training exercise, as we wanted to evaluate whether the user interface was simple enough that it could be used without prior training. Participants were offered the option to use earphones during the tests, rather than listening to the tablet’s speaker. Only Candace and Donald decided to use earphones. Participants were given a chance to ask questions about the system and the experiment, after which they were accompanied to the Science Hill – East bus stop, located about 150 meters away from the Engineering 2 building. This instrumented bus stop is visible in the top left of Fig. 3, marked by a pink circle (a picture of this bus stop is shown in Fig. 2). The app was then started and the tablet handed to the participant, who was instructed to select the Science Hill – East AP for connection, and then to select East Remote Parking – East as final destination (shown by a pink circle in the bottom right of Fig. 3 – see also Fig. 2), using the tap and swipe interface described in Section III.B.

While waiting for the bus, participants were encouraged to occasionally interrogate the system, asking for the waiting time till bus arrival. Once the bus arrived and the participant received confirmation by the system that this was indeed the desired bus, the participant was accompanied inside the bus, where he or she took a seat in one of the front seats reserved for people with disabilities. During the trip, the participant was informed by the app about each upcoming bus stop. Note that

the same information was also announced by the speakers in the bus; however, our participants were able to hear the announcement multiple times, if desired, from the tablet. The participant was asked to pull the cord to call the final stop when he or she determined that the stop was approaching. Once arrived at destination, the participant was accompanied outside the bus, where he or she waited until the system announced that it had disconnected from the bus AP and would go in standby mode. The participant was then accompanied to the instrumented bus stop “Science Hill – East”, located across the street (see Fig. 2 and 3), and asked to wake up the application again (by a tap-and-hold gesture). The whole process was then started again, with the sole difference that the final destination to be selected was Science Hill – West. This leg of the route is shown by a pale blue thick line in Fig. 3. The whole test (including waiting for the busses to arrive and traversing the route eastward and westward) took between one and two hours. Pictures and videos were taken while the participants interacted with our system. At the end of the test, each participant was accompanied back to the Engineering 2 building, where he or she participated in a semi-structured interview (all interviews were audio recorded).

V. INTERVIEWS WITH THE PARTICIPANTS

Semi-structured interviews were conducted after each study. Questions ranged over the use of public transportation by the participants, the perceived accessibility problems of public transit systems, the strategies used by the participants while traveling by bus, the perceived benefits and shortcoming of the system that was just tested, and suggestions for improvement. We report a summary of the interview results, divided into two sections: comments on the accessibility and usability of public transportation as perceived by our participants, and comments/feedback on our system. Each section is organized around a number of main themes that emerged from the interviews.

A. Accessibility and Usability of Public Transit

Catching the correct bus. As a general rule, all of our participants ask for the bus number to the driver of an oncoming bus. Bill said that he also listens to the acoustic announcement that is often produced when the bus pulls over and the doors open. This is not always easy in certain stops, where multiple busses may pull in at the same time. In these situations, it may also happen that a bus may leave before the passenger manages to reach it. Indeed, all of our participants reported that, on occasion, bus vehicles simply drive by a stop without pulling over.

Determining when to exit the bus. All of our participants listen to the acoustic announcements inside a bus to maintain awareness of their location. In addition, all participants except for Bill also make sure to let the driver know about their final destination (and possibly take a seat next to the driver, if there is one available, to make sure that the driver doesn’t forget about them). Bill is well acquainted with the routes in Santa Cruz, so he only informs the driver of his destination when traveling in nearby San Jose. This is because the Santa Cruz

METRO system announces all stops, whereas the vehicles managed by the Santa Clara Valley Transportation Authority (VTA), which covers the San Jose area, do not announce minor stops. All participants except for Bill experienced situations in which, even after informing the driver about their final destination, the driver neglected to warn them in time, resulting in them missing their stop.

Other accessibility issues. Albert noted that sometimes bus vehicles cannot pull close enough to the curb, which complicates the process of exiting the bus (he needs to step into the street before stepping onto the curb). He also lamented a general lack of education by the drivers about giving informative directions in a way that is useful to blind travelers. An accessibility issue mentioned by Albert is that bus stops are not easy to locate: he said that he may not be certain that he has reached a bus stop until he accidentally hits a bench or a shelter. Another undesirable situation, as pointed out by Donald, occurs when a blind passenger waits for the bus while sitting on a bench, and, unaware that the desired bus has arrived, does not stand up. In this situation, the bus may simply not stop. Donald, who has poor hearing, found that the biggest accessibility problem is when the desired stop is not announced, or the announcement is too low in volume, or cannot be heard because of ambient noise.

B. Comments and Feedback on the PTA System

General. All participants appreciated the functionalities provided by our system (while recognizing that this is only an early prototype), and declared that they would use it if it were universally available. Albert went so far as to claim that this was the most useful prototype he had tested in years. However, he commented that this system should be recommended only for experienced and independent travelers – a blind person must have already developed good mobility skills for this system to be useful. Candace commented that the tablet would be too big for regular use, but understood that the system could be implemented on a regular smartphone. All participants commented positively on the functionality of the system that allows one to select the destination bus stop. In particular, Bill appreciated being able to input this information while at the bus stop, rather than inside the bus, where the noise level is higher and it may be more difficult to operate the tablet. According to Albert, the system functionality that allows for spoken information to be repeated is an important feature, especially when, due to loud noise, the information was not heard the first time around.

Pre-warning. Among the functionalities provided by the system, the warning produced when the bus reaches the stop before the final destination was particularly appreciated by all participants. In the words of Albert, “this alone is worth the price of the app”. Bill noted that the one stop-away warning gives one time to “tie up loose ends”, especially if one has been in the bus for a little while or on an unknown route. He said that he often finds himself in situations in which the stop is announced and he suddenly needs to exit the vehicle. Donald recommended that the system be customized to, for example, announce when the traveler is 5 stops away from

destination. Bill thought that being able to query the system to know how many stops there are before one’s destination could be useful. Albert remarked that he would like the system to announce the distance (e.g. 2 miles) till the destination, rather than the number of stops.

Bus arriving – Announcement. As mentioned in Sec. III.B, when the desired bus is arriving at a bus stop, our app generates a synthetic speech warning to alert the user waiting at that stop. In practice, this warning is produced approximately 5 seconds before the bus pulls in and opens the doors. While the participants appreciated this functionality, there were some strong opinions about exactly when this warning should be produced. Candace said that the announcement in the current system is given too late – or better, that it would be desirable to be warned about the bus arrival with more advance (perhaps 10 seconds), and then again once it has arrived. Bill thought that it would be desirable to know in advance when the bus is arriving (e.g., when the bus is 5 minutes away). Donald thought that this announcement should be made at least 30 or 40 seconds before the bus arrives, or perhaps when the bus leaves the previous bus stop. In addition, several participants noted that if two busses arrive at the same time at the stop, our system would be unable to help one figure out which vehicle is the desired one. A possible solution to this problem could be to install iBeacons (Bluetooth low energy beacons) on the vehicles [18]. Given the short transmission range of these devices, it should be possible to ascertain which bus is which by analyzing the received signal power.

Desiderata. Albert mentioned that it would be very useful to know the transmission range of the bus stop AP, as this would help one understand the distance to the stop. This comment was echoed by Bill, who said that it would be very useful if this system could give precise directions to the bus stop location.

Indeed, according to our participants, finding the exact location of a bus stop is extremely challenging for a blind person. According to Albert, blind users at a bus stop need to figure out the distance between their location while waiting for the bus and the exact place where the bus can be boarded. For example, one of the bus stops in our study (Science Hill – East) has a shelter with a bench that is located almost ten meters away from the edge of the curb where bus vehicles pull in. This information is important for a blind person, who needs to plan when to get up from the bench upon arrival of the bus, and where to move to catch it. As another example, Bill noted that some bus stops have a bench and some don’t; accessing this information would be important, as this would save one from spending time searching for a bench that is not there. It is important to note that our PTA system cannot provide this level of spatial information. It can only determine whether an AP is within transmission range, which, as explained later, can have a radius of 50 meters or more. Again, iBeacons placed at bus stops could be used to support more fine-grained localization.

Bill noted that accessing the list of bus lines through a certain stop would be very useful, while Albert suggested that

when waiting for a bus at a stop, one may want to know whether there may be an express bus going to the same destination following the next upcoming bus. Bill also suggested enhancing the system so that a bus driver could be informed that a blind passenger is waiting at a certain stop, to make sure that the driver pays special attention to this passenger.

Candace suggested that, once arrived at destination, the system should give some information about the nearby streets and intersections – enough to help one situate oneself upon exiting the bus. Perhaps the system could also announce the name of the roads traversed by the bus on its route.

VI. CONCLUSIONS

From our interviews with the participants, and from observations during the experiment, it was clear that public transit systems still have a number of issues related to accessibility. Using public transportation is indeed challenging for a blind passenger, as our participants' shared experience has highlighted. While it may happen to everyone to miss the bus or to miss the desired stop, these occurrences are much more likely to happen to blind travelers.

Our participants enjoyed all functionalities offered by the system, and generally gave us very encouraging reviews. A criticism that was shared by all participants regarded the short advance notice provided when a desired bus is approaching the stop the user is standing at. All of our participants felt that, while this feature is very useful, notification should be produced earlier, in order to give them more time to prepare to board the bus. Of course, if real-time information is available (from bus trackers such as OneBusAway [10] or NextBus), early arrival notification would be easy to implement as an additional feature to our system.

One shortcoming of the proposed PTA system is that WiFi APs must be installed at bus stops and within bus vehicles, which may be costly for the travel agencies. However, we note that in some cases, WiFi APs are already installed inside bus vehicles, typically on long-haul bus lines. Installation of WiFi APs at bus stops has also been planned in some cities. If a WiFi AP is already available, upgrading it to support services such as our PTA would be relatively inexpensive.

Several of the same functionalities offered by our PTA system could be provided by a smartphone app that uses GPS data for localization, and has access to timetables and possibly real-time information from the Internet. This solution would not call for any special infrastructure, but it would need good Internet connectivity and GPS signal. (Note that our system does *not* require Internet connectivity or access to the user's phone's GPS.) In addition, a purely smartphone-based application may not be able to notify the user in real time when the desired bus has arrived at a bus stop. Regardless of the technology ultimately chosen, our experiments have shown that a personal travel assistant, implemented as a smartphone app, has great potential to improve travel-related information access for blind users, and our study has highlighted the main functionalities that such a system needs to offer to be really useful to blind travelers.

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