

# A Public Transit Assistant for Blind Bus Passengers

**Germán H. Flores**  
University of California,  
Santa Cruz

**Roberto Manduchi**  
University of California,  
Santa Cruz

Public transit is the key to independence for many blind persons but, despite recent progress in assistive technology, remains challenging for those without sight. To this end, the authors developed a prototype mobile application that communicates information via Wi-Fi access points installed in buses and at bus

stops to help blind bus passengers reach their destination. A user study of the system yielded insights into general accessibility issues for blind public transit riders as well as ways to improve the proposed system.

Public transit plays a critical role in the independence of blind persons, providing more opportunities for employment, education, leisure, and socialization.<sup>1</sup> Yet, blind travelers continue to face difficulties,<sup>2–4</sup> despite accessibility advances mandated by legislation such as the Americans with Disabilities Act (ADA). In particular, access to travel-related information, which contributes to comfort and safety, might be difficult for those who cannot see. A passenger needs to ascertain which bus, train, or subway line to take, when the vehicle departs, and where to board it. While riding, passengers need to be aware of progress toward their destination so they have sufficient time to prepare to exit the vehicle when it arrives at the desired stop.

Nonvisual (acoustic) modalities can facilitate some of these tasks. For instance, the ADA prescribes that buses announce stops at major destinations and intersections, transfer points, stops requested by disabled riders, and in general frequently enough to allow visually impaired passengers to orient themselves ([dredf.org/ADA/tg/stop.shtml](http://dredf.org/ADA/tg/stop.shtml)). In practice, stops are sometimes not announced or announced only at the last second. Moreover, some passengers, particularly those with hearing impairments, might find it difficult to hear announcements produced by the vehicle's speakers, especially when there is loud noise from the environment. Individuals who are unsure or anxious, or have some cognitive impairment, might benefit from hearing the same announcement repeated multiple times.<sup>4</sup>

## PTA SYSTEM FOR BLIND TRAVELERS

We developed a prototype public transit assistant (PTA) system to increase information awareness of blind travelers, specifically those riding buses.<sup>5,6</sup> The system uses Wi-Fi access points (APs), installed in vehicles as well as at bus stops, to communicate with users' Android

smartphone or tablet. It requires no Internet connection and does not need to use the device's GPS. Passengers within Wi-Fi range of a bus stop AP are notified about the bus lines transiting through that stop, their timetables, and possibly other location-based information. While inside a bus, passengers might receive information from the vehicle's AP about current progress along the route. The system allows for preselection, via a specially designed accessible interface, of the desired bus line and destination. Passengers waiting at a bus stop receive a notification when their desired bus is approaching; once inside the bus, they are informed well in advance of when the bus is about to arrive at their destination stop. Information is produced as synthesized speech. Users can request the system to repeat its last announcement as well as query the system about other available information.

We tested our PTA system in a realistic scenario with four blind participants, who operated it while riding two AP-equipped buses along a specific route on the campus of the University of California, Santa Cruz (UCSC). Their task was to select specific destinations and exit the bus at the designated stops. After the experiment, we conducted a semi-structured interview of the participants in which they shared their experience, discussed general accessibility issues, and provided feedback about our system. The user study and interviews highlighted some of the problems faced by blind individuals while using public transportation, and provided a critical assessment of the functionalities of our system and ways it could be improved.

## RELATED WORK

Several researchers have addressed the problem of improving information access to travelers with sensorial impairments.<sup>4</sup> For example, Shiri Azenkot and her colleagues<sup>4,7</sup> studied the use of Braille notetakers by blind and deaf-blind travelers to obtain arrival times generated by the One-BusAway system.<sup>8</sup> The ABLE (Accessible Bussing through Location Estimation) Transit system<sup>9</sup> implemented access to location-contingent data in General Transit Feed Specification (GTFS) format, estimating the user's location via GPS. Likewise, Ubibus<sup>10</sup> was a proposal to enhance existing bus services via ubiquitous computing by facilitating transit information access by blind persons. The Accessible Bus System<sup>11</sup> used Bluetooth beacons to inform users when a desired bus has arrived. Bluetooth beacons were also used in the URNA (Universal Real-Time Navigational Assistance) project to provide blind users with information about the status of a traffic light at an intersection.<sup>12</sup>

Other projects have considered the needs of travelers with cognitive impairments.<sup>13–15</sup> For example, the Travel Assistance Device<sup>16</sup> used the traveler's device'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. João de Sousa e Silva and his colleagues<sup>17</sup> developed a similar system. Unlike these efforts, we designed our PTA system from the ground up with the goal of supporting visually impaired passengers throughout their entire travel, from the moment they arrive in the vicinity of their first bus stop to the time they reach their destination bus stop.

Besides accessing trip-related information, visually impaired passengers often have difficulty recognizing a bus stop or orienting themselves in a transit hub. Standard mapping services such as Google Maps and accessible GPS apps such as BlindSquare or Sendero's Seeing Eye GPS can be used for this purpose, but they have critical shortcomings. For example, Google Maps provides the location of bus stops but not descriptions of their layouts. 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 their desired bus stop or at a bus stop across the street. The StopFinder project<sup>18,19</sup> created a database of detailed descriptions of layouts of bus stops, collected via crowdsourcing. Markus Guentert<sup>20</sup> designed an iPhone app to allow blind persons to explore the layout of a train station. Kotaro Hara and his colleagues<sup>21</sup> presented a system that uses

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crowdsourcing to build a database of bus stop locations that includes layout descriptions. As our interviews highlighted, this type of spatial information can be very useful for blind passengers.

## CLIENT–SERVER ARCHITECTURE

In our PTA system, each in-vehicle and bus stop AP is essentially a router that acts as a server, and communicates information with a client application running on an Android device. This app manages connections, communication, and overall user interaction. 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.

For our study, we designed a custom Android app and implemented it in a Nexus 7 tablet. This app incorporated

- Wi-Fi connectivity requests including connecting, disconnecting, and switching between in-vehicle and bus stop APs;
- multi-touch gesture interactions with the user such as single tap, press-and-hold, and swipe;
- local database queries to extract relevant bus time schedule information and a list of instructions and confirmations; and
- text-to-speech synthesis to convert written instructions, confirmations, and any other information from the database into speech.

During operation, the mobile app first scans for available networks to verify whether they are within actual or effective range. *Actual* range is defined as the maximum distance (~64 m) at which the client app detects that an AP is within the vicinity but might not be able to communicate. *Effective* range is the distance (~50 m) at which an AP is detected and able to communicate with the client app. When the client is within the effective range of an AP, it sends a connection request and waits for an acknowledgement from the AP. If acknowledged, the connection remains open and the AP sends data to the client.

## USER INTERACTION

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

In a typical application scenario, 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 might occur when, for example, two bus stops face each other across the street), the user is asked to select the desired AP. Specifically, the app lists all APs within range along with their names (for example, "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 query the system to hear the remaining estimated time. As soon as the bus arrives and is within the user device's Wi-Fi range, the system switches the connection to the bus's in-vehicle AP and informs the user that his or her bus has arrived. The user is then expected to enter the bus and find a seat. The in-vehicle AP updates the app about the current bus location as well as upcoming stops the vehicle is approaching (using the optional GPS device for positioning). At any time, the user can review the last information produced by the app and, if desired, request to have this information repeated multiple times. The user receives a special notification once the vehicle approaches the stop before the desired one. We introduced this feature to ensure that users would have enough time to pull the request stop cord, stand up and move towards the door, and so on. Upon arrival at the desired 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.

## USER STUDY

Here we describe our PTA system user study, including the participants, AP installations, and methodology.

### Participants

We recruited four blind persons for our user study, shown in Figure 1. To preserve their anonymity, we refer to them by fictional names.



Figure 1. Blind participants in our public transit assistant (PTA) system user study. Clockwise from top left: “Albert” interacting with the PTA application on his tablet; “Bill” being informed that his desired bus is approaching; “Donald” pulling the stop request cord; “Candace” waiting to hear from the system whether the approaching bus is the desired one.

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

Bill is a 58-year-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 assistive 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, three to four times per week. He never uses paratransit services.

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



Donald is a 67-year-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. Donald is fairly proficient with technology and loves his iPhone. He is highly mobile and used to travel around the world for business. Donald uses a long cane as a mobility device. In recent years, he has only used private transportation or taken public transportation when 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.

## AP Installations

We instrumented three bus stops on the UCSC campus and one bus with APs. As Figure 2 shows, two of the bus stops (Science Hill–East and Science Hill–West) face each other in the upper part of the campus; the third bus stop (East Remote Parking–West) is in the lower part of the campus. Figure 3 shows a map of the routes included in our study and the bus stop locations. The reason for instrumenting two bus stops facing each other is that a user located at one bus stop would be in the Wi-Fi 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.



Figure 2. Bus stop Wi-Fi access point (AP) locations in our user study. Top: Science Hill–East (left) and Science Hill–West (right) face each other. Bottom: East Remote Parking–West.

## Methodology

We tested participants individually during February and March 2015. We purposely decided not to perform a “dry run” exercise, as we wanted to evaluate whether the UI was simple enough to be used without prior training. Participants had the option to use earphones during the tests rather than listen to the tablet’s speaker. Only Candace and Donald decided to use earphones.

We gave each participant a chance to ask questions about the PTA system and the experiment, after which a researcher accompanied him or her to the Science Hill–East bus stop, located about 150 meters away from the Engineering 2 building. We then activated the app and handed the tablet to the participant, who was instructed to select the Science Hill–East AP for connection and then East Remote Parking–East as the destination, using tap and swipe gestures.

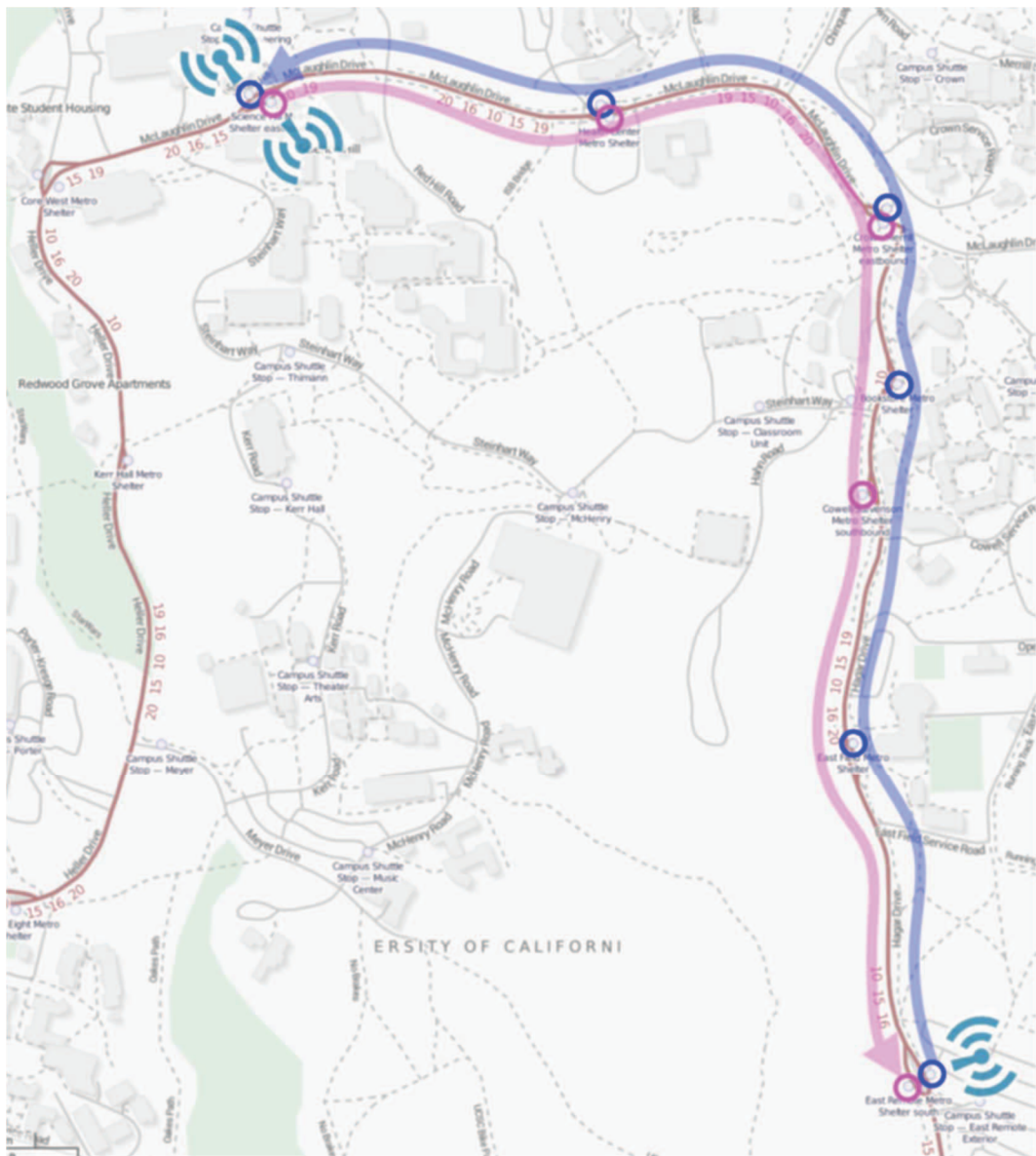


Figure 3. Map of the bus routes on the University of California, Santa Cruz campus included in our user study. The eastward and westward routes are pink and light blue, respectively. Colored circles indicate bus stops, with the characteristic Wi-Fi symbol indicating the AP locations.

While waiting for the bus, participants were encouraged to occasionally query the system for the remaining wait time. Once the bus arrived and the system confirmed that this was indeed the desired bus, the researcher accompanied the participant inside the vehicle, where he or she took a seat in one of the front seats reserved for people with disabilities.

During the trip, the system informed the participants about each upcoming bus stop. Speakers in the bus announced the same information, but the participants were able to hear the announcement multiple times, if they so desired, from the tablet. The participants were asked to pull the stop request cord when they determined that the destination stop was approaching.

Upon arriving at the destination, the participant and researcher exited the bus and waited until the system announced that it had disconnected from the bus AP and was in standby mode. Accompanied by the researcher, the participant then walked to the East Remote Parking–West stop across the street and was instructed to awaken the app with a tap-and-hold gesture.

For each participant, the process was then repeated, with the sole difference that the final destination to be selected was Science Hill–West. The entire test, including waiting for the buses to arrive and traversing the route eastward and westward, took between one and two hours. The researcher took photos and videos of the participant interacting with our system. At the end of the test, the researcher accompanied the participant back to the Engineering 2 building and conducted a semi-structured interview. All interviews were audio recorded.

## PARTICIPANT INTERVIEWS

The interview questions ranged over the use of public transportation by the participants, the accessibility problems of public transit systems, the strategies used by the participants while traveling by bus, the benefits and shortcomings of our PTA system, and suggestions for improvement.

### Accessibility and Usability of Public Transit

Three themes emerged from the participants' responses to questions about public transit accessibility and usability.

#### Catching the Correct Bus

As a general rule, all of the participants ask the driver of a bus that has just arrived for the bus number when they hear the doors open. Bill said he also listens to the acoustic announcement that is often produced by a bus when it pulls up and its doors open. This is not always easy at certain stops, where multiple buses might arrive at the same time. In these situations, a bus could leave before a visually impaired passenger manages to reach it. All of our subjects reported that, on occasion, buses drive by a stop without pulling over.

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#### Determining When to Exit the Bus

All of the participants listen to the acoustic announcements inside a bus to maintain awareness of their location. In addition, all except Bill make sure to let the driver know about their final destination and possibly take a seat next to the driver, if one is available, to make sure that the driver does not forget about them. Bill is well acquainted with the bus routes in Santa Cruz, so he only informs the driver of his destination when traveling in nearby San Jose. This is because Santa Cruz METRO system vehicles announce all stops, whereas buses operated by the Santa Clara Valley Transportation Authority in the San Jose area do not announce minor stops. All participants but 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 at some bus stops, buses sometimes cannot pull up close to the curb, which forces him to step into the street when entering or exiting the vehicle. He also lamented a general lack of education among drivers about giving useful guidance to blind travelers. In addition, Albert said that bus stops are not easy to locate: he might not be certain that he has reached a bus stop until he accidentally walks into a bench or shelter. Donald pointed out another undesirable situation: a blind passenger sitting on a bench might be unaware that the desired bus is approaching and does not stand up, causing the driver to continue without stopping. The biggest accessibility problem for Donald, who has poor hearing, is not being able to hear the announcement of his desired stop due to ambient noise.

## PTA System Feedback

All participants in our user study appreciated the functionalities provided by our system and declared that they would use it if it was universally available. Albert went so far as to assert that it was the most useful prototype he had tested in years. However, he only recommended the system in its current form for experienced and independent travelers with good mobility skills. Candace commented that the tablet would be too big for regular use, but was satisfied that the system could be implemented on a smartphone. All of the participants praised the ability to select the destination stop. In particular, Bill appreciated being able to input this information while waiting for the bus, rather than inside the vehicle where the noise level is higher and it might be more difficult to operate the device. For Albert, the ability to repeat spoken announcements is an important feature, especially when, due to loud noise or low speaker volume, the information was not heard the first time.

### Destination Stop Pre-warnings

Among the most popular functionalities of our system is the warning produced when the bus reaches the stop before the final destination. In Albert's words, "this alone is worth the price of the app." Bill noted that the one-stop-away warning provides time to "tie up loose ends," especially if one has been in the bus for a while or is on an unknown route. He said that he often finds himself in situations in which the stop is announced and he suddenly must exit the vehicle. Donald recommended that the system be customized to announce when the traveler is, say, five stops away from the 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—for example, two miles—until the destination, rather than the number of stops.

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### Bus Arrival Announcements

As indicated earlier, our system generates a synthetic speech alert to users waiting at a bus stop to let them know that their desired bus has arrived. In practice, this occurs approximately five seconds before the bus pulls up and its doors open. While the participants appreciated this functionality, they had strongly different opinions about the alert's timing. Candace said that the current system's announcement is a little too late—she preferred 10 seconds. Donald thought that it should be at least 30 to 40 seconds before the bus arrives, or perhaps when the bus leaves the previous stop. Bill preferred about 5 minutes advance notice. In addition, several participants noted that if two buses arrive at a stop at the same time, our system would be unable to distinguish the desired one. A possible solution to this problem is to install Bluetooth low-energy iBeacons on the vehicles.<sup>22</sup> Given these devices' short transmission range, it should be possible to identify buses by the received signal power.

### Other Desiderata

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

Indeed, according to our participants, finding a bus stop's exact location is extremely challenging for a blind person. According to Albert, blind travelers at a bus stop need to figure out the exact distance between where they are waiting for the bus and where they must board the bus. For example, the Science Hill–East stop has a shelter with a bench that is almost 10 meters away from the edge of the curb where buses pull up. A blind person needs to plan when to get up from the bench upon the bus's arrival, and where to move to catch it. As another example, Bill noted that



some bus stops have a bench and others do not; knowing this information would save one from wasting time searching for a bench that is not there. Our PTA system currently cannot provide this level of spatial granularity; it can only determine whether an AP is within transmission range, which can have a radius of 50 meters or more. Again, iBeacons placed at bus stops could support more fine-grained localization.

Bill noted that accessing the list of bus routes through a certain stop would be very useful. Albert said that when waiting for a bus at a stop, it would be helpful knowing whether the upcoming bus would be followed by an express bus going to the same destination. Bill also suggested enhancing the system to inform bus drivers that a blind passenger is waiting at a certain stop, to ensure that they pay special attention to this passenger. Candace added that once a user has arrived at his or her destination, the system should provide enough information about nearby streets and intersections to help the user become situated after exiting the bus. The system could also announce the names of roads traversed by the bus on its route.

## CONCLUSION

Our user study made it clear that public transit systems still have numerous accessibility issues. Using public transportation is indeed challenging for blind passengers, as our participants' shared experiences revealed. While anyone could miss a bus (or train or subway) or their desired stop, these occurrences are much more likely to happen to blind travelers.

The participants enjoyed all of the functionalities offered by our prototype PTA system, and generally gave us very encouraging reviews. However, they all questioned the short advance notice given for arriving buses—while useful, the notification should be earlier to give users more time to prepare to board the bus. This would be easy to implement in our system by integrating real-time information from bus-tracking apps such as OneBusAway or NextBus.

A more significant challenge for wide-scale deployment is the need to install Wi-Fi APs at bus stops and within vehicles, which could be costly for transportation agencies. However, Wi-Fi APs are installed in many buses, typically on long-haul routes, and some cities have already installed Wi-Fi APs at selected bus stops, with more to come. If a Wi-Fi AP is already available, upgrading it to support services such as our PTA would be relatively inexpensive.

Several of our PTA system's functionalities could be provided by a smartphone app that uses GPS data for localization and has access to bus 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 a strong GPS signal—recall that our system requires neither. In addition, a purely smartphone-based app might 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 study shows that a PTA, implemented as a mobile app, has great potential to improve travel-related information access for blind users, and it has highlighted the main features that such a system needs to be really useful to blind travelers.

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## ABOUT THE AUTHORS

**Germán H. Flores** is a research scientist at IBM Research–Almaden. His research interests include indoor navigation using inertial sensors and Bluetooth Low Energy beacons. While conducting the research described in this article, Flores was a PhD student at the University of California, Santa Cruz (UCSC), from which he received his doctorate in computer engineering. He is a member of the Golden Key International Honor Society, Tau Beta Pi Honor Society, and Upsilon Pi Epsilon Honor Society. Contact him at [ghflores@us.ibm.com](mailto:ghflores@us.ibm.com).

**Roberto Manduchi** is a professor of computer engineering and the cofounder and current director of the Computer Vision Lab at the Jack Baskin School of Engineering at UCSC. His current research interests are in assistive technology for people with visual impairments. Manduchi received a PhD in electrical engineering from the University of Padua. Contact him at [manduchi@soe.ucsc.edu](mailto:manduchi@soe.ucsc.edu).