ioCane: A Smart-Phone and Sensor-Augmented Mobility Aid for the Blind

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ABSTRACT

We present the design, implementation, and early results of ioCane, a mobility aid for blind cane users that uses detachable cane-mounted ultrasonic sensors connected to a circuit board to send contextual data wirelessly to an Android phone application. The system uses the built-in mobile phone modalities of vibrations and chimes to alert the user to object height and proximity. We believe this plug-and-play solution for visually impaired users has the potential to enhance user mobility and object avoidance with a minimal learning curve. A pilot study testing the performance of the ioCane with blind cane users showed a 47.3% improvement in obstacle avoidance. To our knowledge, the ioCane is the first sensor-based mobility assistance system to integrate natively with a mobile phone without any modifications to the phone or the system, as well as the first system of its kind to be evaluated by actual visually-impaired cane users.

ACM Classification Keywords

H.5.2 Information Interfaces and Presentation: User Interfaces

Author Keywords

Assistive Technology, Mobile Computing, Ultrasonic Sensing

INTRODUCTION

According to recent statistics from the World Health Organization, 285 million people are visually impaired worldwide: 39 million are blind and 246 million have low vision [26]. Increasing mobility, safety, and independence for the visually impaired is of significant importance, making it a frequent research topic. Several mobility aids for the blind exist, although the blind cane (or white cane) is lightweight, cheap, and relatively sturdy, making it by far the most widely used. However, a typical white cane does have some drawbacks, namely a substantial 'hidden cost' of learning how to use the cane effectively (≈100 hours of training time), and that the user can only sense objects that the cane touches directly. Since canes are held out in front of the user and swept along the ground from side to side, only objects close to the ground and within the range of the cane (normally 3-5 feet) will be detected, making overhanging obstacles (e.g. tree branches, sign posts) impossible to detect. An intensive effort over the last 40 years has gone into technologically-based assistance for the blind, and the use of ultrasonic sensors in this pursuit is nearly as old. Yet widespread adoption of electronic travel aids (ETAs) has failed to manifest. Of the 25.2 million people in the U.S. who reported significant vision loss in 2008 [22], only an estimated 19,500 were users of ETAs [10]. This slow adoption rate of ETAs has been attributed to lifestyle incompatibilities, low quality of information about specific ETAs, and the high cost of most ETAs[8]. Our objective was to design a device that could detect overhanging objects while also fostering wider adoption among visually impaired cane users. The ioCane system was designed after preliminary interviews with 15 blind cane users in order to best identify pain points and potential areas for improvement in cane design. In this paper we present our first prototype of the ioCane: a wireless, lightweight ($\leq$ 400 grams), inexpensive (less than \$200 USD) system designed to snap onto a users existing white cane that interfaces with an off-the-shelf Android mobile phone to provide integrated sensory feedback to visually impaired users. To our knowledge, the ioCane is the first sensor-based mobility assistance system to integrate seamlessly with commodity mobile phones without any modifications, as well as the first system of its kind to be evaluated by visually-impaired cane users.

RELATED WORK

Assistive technology researchers have been investigating ways to aid the visually impaired for many years. The use of sonar as a potential aid for the blind dates back to at least the mid-seventies [15] [17], while recent work more closely related to the ioCane falls into two categories: those that use ultrasonic sensing as the primary sensory augmentation, and those that use other technologies (e.g., radio frequency identification [RFID]).

Ultrasonic systems

Several existing ETAs use ultrasonic sensors as the primary sensory augmentation. Wong et al. describe an integrated system for using ultrasonic sensors on the white cane to estimate distance and provide feedback in the form of audio signals [25]. Cai uses ultrasonics in a time of flight (TOF) approach to integrate an ultrasonic transceiver into the shaft of a white cane, using voice output as feedback [8].

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The GuideCane is an array of ultrasonic sensors on a rolling platform attached to the bottom of a cane to detect and guide the user around obstacles [7].Mandru et al. use ultrasonics attached to a cane and provide tactile feedback through a pulse-width-modulated DC motor [19].Okayasu combines ultrasonics along the cane with a haptic device strapped to the users arm consisting of two vibration motors [21]. At the time of writing, none of the aforementioned systems have gone to market - however, at least three augmented cane systems using ultrasonic sensors are now available commercially. The UltraCane uses two ultrasonic transducers embedded in the handle of the cane to detect objects above and below the user, and provides vibrating buttons as a feedback mechanism [5]. It is currently available for purchase in the U.K. for £635.00 (≈ $1000 USD). The K-Sonar system can be used as a cane attachment or as a stand-alone handheld device (somewhat like a flashlight) [3]. It works by translating ultrasonic feedback into 'tone-complex' sounds, which the user can use to navigate. K-Sonar has distributors globally, and costs $1085 USD. Lastly, a Korean company, Primpo, is marketing a sensor-augmented cane called iSonic [2]. The iSonic uses two ultrasonic sensors for ranging (high and low angle), and includes a color sensor to tell users what color certain objects are. Additionally, a light sensor is used to inform users of the light conditions around them (bright, medium, or dark). The iSonic costs around $800 USD. In contrast, we estimate that the io-Cane attachment could be commercially sold for $200 USD. Even if the user also had to purchase an Android phone, several models exist for under $60 USD [4], still making the price of the ioCane system several times cheaper than existing systems.

Alternative Systems

Although ultrasonic sensing may be the most commercially popular, several other kinds of navigation systems have been developed. Mau et al. [20] proposed an indoor mobility assistance system integrating a RFID-equipped cell phone with tags placed in the environment to generate vocal directions to blind users. Debnath et al.[12] describe a radio-frequency based system whereby switches on the cane can select between channels that correspond to destination locations (e.g., the kitchen). Locations contain an antenna transmitting on the corresponding channel, guiding the user by audio or tactile feedback to the destination. Lahav and Mioduser [16] use a combination of haptic and audio feedback in a virtual environment to produce a mental model of unknown spaces. Loomis et al.[18] describe a modular system composed of a device for determining the users position and orientation, a Geographic Information System (GIS) containing information of their test site for route planning, and a user interface.

Other systems include: infrared (IR) sensors for object detection and avoidance [14], IR sensors combined with RFID and GPS for guidance [27], an RFID-based location and tracking system called SESAMONET [11], and a similar RFID-based system called iCane[9], that relies on tags placed on tactile pathways to track user location. Drishti[13] is a system that uses differential GPS and GIS data to direct users while on a university campus. In general, the radio and RFID systems suffer from the time and cost of installing and configuring a large number of sensors over a wide area before the system becomes useful. While GPS can provide coarse location data, and can be integrated with other systems to provide navigation assistance, it cannot detect objects in the users immediate path. Based on our review of the literature, a combination of audio and haptic feedback generated on data from an array of ultrasonic sensors appeared to be supported by the most promising user testing data as well as a practical price point around which to design our system. Although some ultrasonic systems have become commercialized, current systems are extremely expensive for the average visually-impaired consumer or require the purchase of an entirely new cane. Instead of adapting to a new cane, our aim was to use the cane already in use - making a lower-cost (1/3 to 1/4 of the price), snap-on system like ioCane a desirable alternative. Additionally, none of the aforementioned ultrasonic devices can integrate with Android phones, limiting any real possibility for growth in functionality or performance by leveraging any existing features of a common smart phone.

SYSTEM DESIGN AND ARCHITECTURE

Since human factors considerations are important to any successful design project, we felt especially compelled to familiarize ourselves with the problem space as none of the authors are visually impaired cane users. This section will describe the preliminary research and development of user requirements followed by a description of the system architecture we chose based on the data we collected.

User Requirements

A questionnaire was sent to several local groups including the University's disability services office as well as instructors at various training centers for the blind, asking them to distribute questionnaires (via e-mail) to any willing visually-impaired cane users. We collected demographic data, the types of mobility devices currently being used, how long the user has been using a cane, the kinds of obstacles or objects that are most difficult to detect, any solutions to these difficulties that they could think of, and a few questions about their cell phone use (if they had a phone, what kind, and if no phone, why not). We received 15 surveys back from 9 women and 6 men, aged 20-59 years old (mean 29). All participants stated that canes were their primary mode of mobility assistance, only two stated they had a guide dog, and zero indicated the use of an ETA. Twelve of 15 users had been using a cane for over five years, with some younger participants having started cane use as young as four or five. Most importantly for our design were the pain points on cane usage and what kind of cell phone types and usage patterns were common amongst our target population. The most commonly voiced difficulties with cane usage included dealing with uneven or rough ground ('. . . it catches on irregularities in the surface of the street, walk, hall, etc.', 'getting it stuck in cracks') and detecting objects above the height of the sweep of the cane ('running into objects that are above the level of the cane, ex. overhanging branches', 'It does not help in sensing anything beyond its reach; cars, low-hanging branches'). Moving vehicles and distant, fast-moving objects (e.g. a baseball) were quite problematic and difficult. Detecting and dealing with curbs, especially irregular ones, was also a common problem. Somewhat surprisingly, all of our participants owned cell phones, and a large number of them (12 of 15) had some type of smart phone. This division occurred mostly by age, as 3 of the 4 oldest participants did not own a smart phone. Admittedly, the high number of smart phone users in our group may come from the fact that our respondents tended to be young (average age: 29), and from relatively affluent areas. However, in informal follow-up conversations, we were given the impression that most young visually-impaired cane users owned smart phones of some kind, as they came with many valuable accessibility features included (e.g. speech-to-text and text-to-speech).

We formed a set of design requirements based on this survey data as well as information gleaned from related works. We chose to focus our immediate goal on detecting above-the-cane objects, with a long-term aim of making the system highly extensible by leveraging smart phone capabilities. We avoided focusing on the rough ground problem, as we received feedback that solutions involving a roller ball or other smooth rolling attachment would be unsafe for users that relied on the cane for weight support (as in a walking stick) which many older cane users often do. We also wanted the ioCane to work with a user's existing cane (as cane lengths and styles vary from person to person), be cheaper than comparable ETAs, and be as simple and customizable as possible.

Architecture and Implementation

Based on our design requirements we identified a suitable architecture for an initial prototype. Figure 1 shows an abstracted graph of the ioCane architecture. The keystone of the design is the IOIO board [24]. We use the IOIO to translate the analog signals from the ultrasonic sensors and send this data to our Android phone application (app). The IOIO board does this wirelessly via a connected Bluetooth radio, allowing us to place the IOIO board and the sensors directly on the cane, as well as removing any wires between the cane and the mobile phone. The Android app is then responsible for filtering the incoming sensor data from the IOIO and alerting the user if an object is within a threshold proximity, and at what rough height the object is at. This is done via audio and haptic feedback; with the audio corresponding to the height of the object and the haptic feedback (the vibration motor on the phone) corresponding to the proximity of the object.

Housing and Electronics

In order for the ioCane to work reliably, the IOIO board, sensor array, and 9V battery had to fit on a variety of canes in such a way that the electronics would be secure, sturdy, and removable (in case the user wanted to use the cane without the attachment). All these requirements had to be met without obstructing or interfering with the natural movements of the user or of the cane, and without permanently altering the cane itself. This necessitated the design and construction of a custom enclosure for the electronics. The enclosure design (see Figure 2) contains three parts: an inner section which can press-fit around the handle of most canes and provides the angled platforms for the forward-facing sensors to rest upon (thus ensuring the angle never changes) and an outer shell that snaps together over the inner section, providing protection for the electronics and the battery. The dimensions of the housing are roughly 4cm wide by 14cm long (along the cane) x 6.5cm high (centered on the cane). The housing was designed in SolidWorks and then 3D-printed in ABS plastic, making it very durable and lightweight.

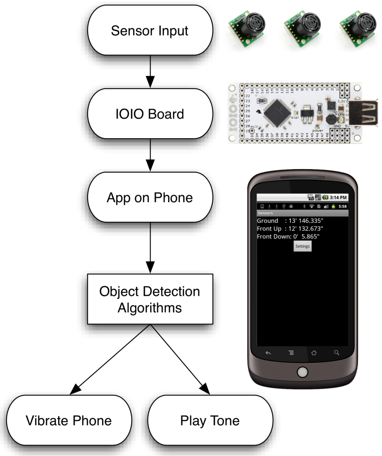


Figure 1: Basic architecture of the ioCane system.

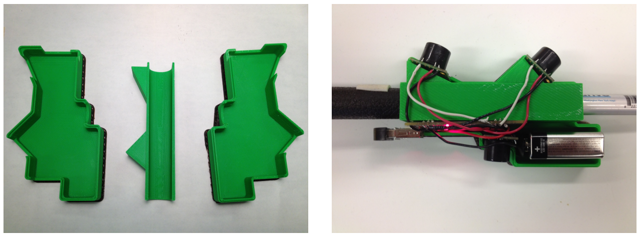


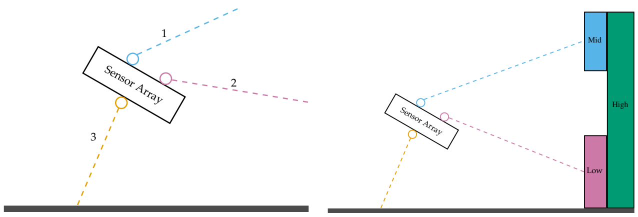
Figure 2: The three sections of the ioCane housing (left) and ioCane housing open to show IOIO board and sensors (right).

Sensor Input

The ioCane system uses three Maxbotix LV series ultrasonic sensors for obstacle detection. Figure 2 shows sensor placement within the ioCane enclosure and on the cane. This placement was designed to detect objects in front of the user and to provide ternary classification as to the height of a detected object: low and not high (e.g., a dog), high and not low (e.g., an overhanging tree branch), or an obstacle that spans both low and high (e.g., a wall).

- **Upward Sensor:** Sensor 1 from Figure 3(a). This sensor is primarily used to detect objects off the ground that could potentially obstruct the user, such as low hanging tree branches or low ceilings.

- **Downward Sensor:** Sensor 2 from Figure 3(a). This sensor is used to detect objects on or slightly above ground level. The range extends further than the cane by roughly a meter, as well as detecting low objects that do not reach the ground (e.g., the side of a table).



(a) Sensor Array (b) Aural Feedback Ranges

Figure 3: Sensor placement on the cane (a) and tonal correspondence to height (b).

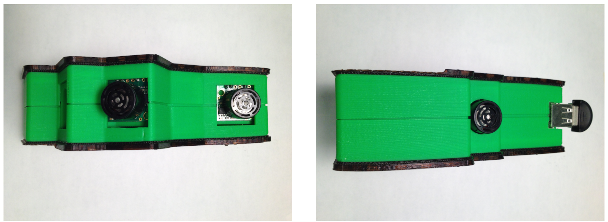


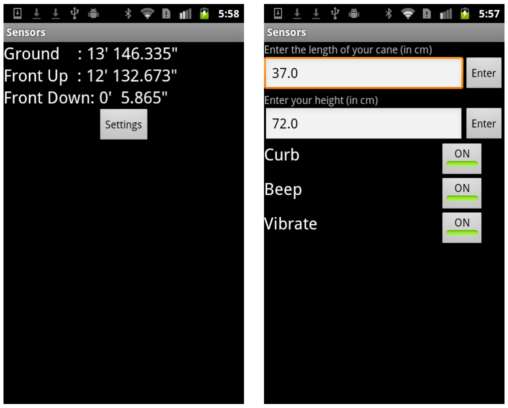
Figure 4: (Left) Front View: with two forward-facing ultrasonic sensors. (Right) Back View: the ground sensor and Bluetooth radio.

- **Ground Sensor:** Sensor 3 from Figure 3(a). This sensor is used for internal calibration of the sensor array. The motivations behind using this sensor are elaborated in the Dynamic Calibration subsection.

The IOIO board is mounted within the enclosure along with the three ultrasonic sensors and a 9V battery. The ground-facing ultrasonic sensor is visible to the left of the battery with the IOIO board fitting snugly between the ground sensor and the cane. The two forward-facing sensors are mounted on the anterior of the ioCane housing. Figure 4 shows the front and back views of the ioCane attachment with the housing pieces attached. The shell has openings to expose the ultrasonic sensors so they may operate unimpeded.

Android Application

Our primary concern with the design of the Android app was to write a simple application that performed the functions of translating sensor data and providing audio and haptic feedback in a timely and reliable manner. We felt that due to the high number of smart phone users amongst our target population who have developed individualized customizations and usage patterns, the existence of system-level accessibility options, as well as 3rd-party accessibility applications such as Georgie [1], we were actually better off not making too many customizations for accessibility, but instead focusing on functionality and customization. The application itself has two screens: the main screen and the settings screen. The main screen shows the readings from the three ultrasonic sensors in real-time and has a single button for entering the settings screen. As well as being a useful debugging tool, we felt that having a live read-out of the sensors could be useful for end-users or friends helping to set up the system. The settings screen contains fields for the user to enter the length of their cane and their height (in centimeters), as well as three toggles (curb, beep, and vibrate) that control the kinds of feedback the user wishes to receive. The 'curb' toggle is for an experimental curb-detection algorithm (discussed in future work), 'beep' toggles the audio feedback responsible for communicating the heights of obstacles, and 'vibrate' toggles the haptic feedback that indicates the proximity of an oncoming obstacle. The toggle controls were motivated by feedback from some users that they prefer one form of feedback over another, especially in certain situations (e.g., while navigating inside a library a user may want to turn off the audio feedback but keep the haptic feedback on). The ioCane app uses the IOIOLib [6] software library to send the sensor data over Bluetooth from the IOIO to the phone as well as for defining the microcontroller pin numbers and input types we use from the IOIO itself. No separate programming of the microcontroller is necessary as all of the firmware is written in the Android app. Additionally, the application does not require any special permissions, (just the permission to use Bluetooth and to vibrate the phone) and should work on any Android 1.5 or higher phone. We tested the app on 2.3.3, but used no features above Android 1.5. Figure 5 shows screenshots of the Android app: the main screen when connected to the IOIO and the settings screen used to adjust the various features of the application.



Ground : 13' 146.335"
Front Up : 12' 132.673"
Front Down: 0' 5.865"

Enter the length of your cane (in cm) 37.0
Enter your height (in cm) 72.0
Curb ON
Beep ON
Vibrate ON

(a) App connected (b) Settings screen

Figure 5: Screenshots of the Android application

Dynamic Calibration using the Ground Sensor

How the cane is held can change based on the height of the user as well as the length of the cane they use. This means that we cannot depend on a predefined value of the angle the cane makes to the ground. Our system depends on a precise cane-to-ground-angle as we use this to calculate the exact position of the object from the user. In order to make this system work, we placed a third ground sensor which always points to the ground and constantly measures the distance from the sensor to the ground. To ensure that the ground sensor is always facing downward, a thumb-rest was placed on the top side of the cane, by which the user can feel and adjust the cane to ensure correct orientation of the ioCane attachment.

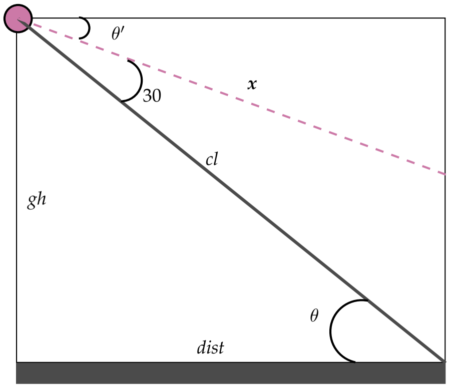


Figure 6: Ground Angle Calculation

Estimating Cane-Ground angle

Another unique feature of the ioCane system is the ability to dynamically determine the end-of-the-cane as seen by the two forward-facing sensors. Since our system works by measuring distances beyond the cane (to detect obstacles), we would like to have a precise estimate of the distance to the end of cane as seen by a given sensor.

Figure 6 shows the angles involved with two sensors. The gh is the length measured from the **ground sensor** and x is the length from the **downward sensor** to the end of the cane; cl is the cane-length; $dist$ is the distance (horizontal distance from the user till the end of the cane) and θ is the angle made by the cane when it touches the ground. Our goal is to calculate x dynamically. We do this since we want to extend the reach of the cane, at the same time, we do not want to preset a value θ, since the ground angle changes between users and even within a single user session. To do this, first we calculate the angle θ using basic trigonometry:

$$\sin\theta = \frac{gh}{cl}$$

which makes:

$$\theta = \text{asin}(\frac{gh}{cl}) \tag{1}$$

With this value of θ, we can now precisely calculate the actual distance of a given object; irrespective of the height of the user. We know,

$$dist = \sqrt{cl^2 - gh^2} \tag{2}$$

Also we know that $\theta' = \theta - 30$, therefore we can show:

$$dist = x.\cos(\theta - 30) \tag{3}$$

Using the values from Equation 1 and Equation 2 in Equation 3, we can now dynamically determine the distance $dist$. Only the length of the cane: cl need be a predefined value. This is the reason that we use the third **ground sensor** in our system. Our Android app has a field where the user can input the length of their cane and thus enable more precise estimates of objects around them, although it is not strictly necessary in order for the system to work effectively.

Ceiling Detection

In a similar manner we also calculate the distance to the ceiling or other high objects that the user can pass under easily. The calculation is focused on the upward sensor and requires the height of the user to be known. Thus our app has an input field where the user can specify their height. Once we calculate the threshold value, we provide user feedback only if objects are closer than the threshold value and thus likely to actually affect the user.

Haptic and Audio Feedback

After having detected objects via the ultrasonic sensors, the ioCane system uses chimes and vibrations to provide feedback to the user via the mobile phone. Although the initial system could have been designed as a standalone device without phone integration by placing haptic and audio components on the cane directly, initial interviews with blind cane users indicated that wearing a device around their neck or in their pocket was preferable to having more weight on the cane itself. By integrating with the phone, we accomplish several goals: the cane hardware becomes more lightweight (presumably making adaptation easier on the user), the feedback can be closer to the user (on their person), thereby allowing for the use of an earbud, and we gain flexibility for future development of system by potentially leveraging some of the phones on-board capabilities (see Future Work for more discussion).

We chose to use the haptic feedback on the phone to indicate the distance of the user from a particular object. Intense vibrations are used to warn the user of any object within 2 feet from the users cane. The vibrations get progressively milder as the distance from the user increases. We cease to vibrate the phone if the object is more than 7 feet from the user. For audio feedback, the ioCane uses different tones generated from the cell phone to provide feedback on the height of the object detected.

We wanted to keep the feedback as straightforward as possible to minimize the learning curve, so we programmed three tones associated with three different heights. We can clearly see the association between tone and height in Figure 3(b). We use a low tone for objects low to the ground, a medium tone to indicate that the object is off the ground but could potentially obstruct the user (e.g. a tree branch); and we use a high tone to indicate obstructions like walls or tree trunks that span from low to high.

EVALUATION

This section discusses the evaluation of the ioCane system through an initial evaluation of our sensor array as well as the results of our user study. We will briefly discuss the evaluation of the ultrasonic sensor array and then move on to discuss the procedure and results of the user study.

Sensor Sub-System

To evaluate the sensor sub-system we first performed a controlled test. The test was to use a 12 inch x 12 inch (30cm) square piece of cardboard as an obstacle held at different heights and tested from various distances from the ioCane. The results of the experiment are shown in Table 1.

Height	Distance from ioCane						
	1’	2’	3’	4’	5’	6’	7’
1’	–	–	VL	VL	VL	VL	–
2’	VL	VL	VL	VH	VL	VL	–
3’	VH	VH	VH	VH	VH	VL	–
4’	VM	VH	VM	VM	VH	–	–
5’	–	VM	VM	VM	VM	–	–
6’	–	VM	VM	VM	VM	–	–
7’	–	–	–	–	VM	–	–

Table 1: Evaluation of the sensor sub-system (measurement is in terms of feet)
V=vibrate; L=Low tone; M=Medium tone; H=High tone

The measurements in the x-axis in Table 1 are the distances from the ioCane sensor array, while the y-axis is the height of the top of the cardboard from the ground. From the Table we can see that if the obstacle is very near to the cane (≤ 2 feet) and very low on the ground (≤ 1 feet) then our system fails to detect it. This represents the case when an object is underneath and closer to the user than the edge of the cane, making detection unnecessary as this also represents the case in which the physical cane is already suited to alerting the user of an obstacle. Additionally, the sensors do not detect high objects at very close proximity (above 5 feet and within 1 foot). Although this did not seem to unduly hamper obstacle avoidance in our study, future ioCane iterations should try to account for these cases. Another interesting finding is that as the beams diverge with distance they cease to overlap. This is a blind-spot in our design, however the beams do not diverge until about 2 meters away from the user. While not ideal, this blind-spot actually became an advantage during user-testing, as users wanted audio feedback only when objects were quite close (i.e., collision was imminent).

User Testing: Procedure

We conducted pilot study with blind cane users to assess whether the ioCane system provided an increase in obstacle avoidance and to gain valuable design feedback. We were able to test with four individuals (3 females), ages 20, 29, 48, and 59. Table 2 shows the data we collected from each user on how long they had been using a cane, how often they used it, the type of phone they had, and their particular vision impairment.

The testing procedure was as follows: we ran the user through a simple obstacle course, with a single 12” by 18” cardboard obstacle at varying heights and distances (heights were centered at 2’, 4’, and 6’, distances ranged from 15’ from start to 30’ from start). The height and distance of the obstacle varied with each run, and were introduced in a random order. To get a sense of baseline navigation performance, participants first ran through the course several times with a normal blind cane without the ioCane. For each run we recorded whether they hit or avoided the obstacle, their time through the course, and observational notes about the run. Test trials proceeded in random order. Since most individuals who are legally blind retain some sight, we provisioned that all users were required to navigate the course wearing blackout shades. This guaranteed that each participant was relying on non-visual sensory feedback throughout the test. While we recognize that this does not realistically represent how an an individual with partial blindness would be navigating their environment, using the blackout shades does correspond to the more realistic setting of how a user might have to navigate their environment at night. After the initial set of runs the users were introduced to the ioCane system. We explained the tonal and haptic feedback and how the feedback corresponded to real-world objects. We then had the users explore the area (not the obstacle course) with the ioCane in order to get a better sense of the device operation. After a participant had indicated that they felt comfortable with the ioCane (exploration times varied between 10-30 minutes), we had the participants navigate the course again, randomizing the distance and height of the obstacle with each run. Obstacle avoidance, time, and observational notes were again recorded for each run.

User	Demographics			
	How Long	Usage	Phone	Vision
1 - F/48	30 yrs	6hrs/day	smile and dial	Fundis Flavimaculitus (Stargart’s disease)
2 - F/59	8 yrs	30min-3hrs/day	$10 basic phone	Retinopathy of prematurity, left eye prosthetic, right eye split screen 20/400-20/600
3 - M/29	1 year	8-10hrs/ day	iPhone 3	5 degree Retinitis Pigmentosa
4 - F/20	15 years	4-5hrs/ week	Alias (semi-smart phone)	Delta 60 Desaturase deficiency, 20/600

Table 2: User demographics by gender/age, length of cane usage, daily/weekly cane usage, phone type, and vision impairment

Figure 7: From left: A picture of the obstacle rig (set at medium height), a user with the ioCane and phone around the neck, and a user trying the ioCane as a handheld device.

User Testing: Results and Discussion

Across all users and all heights and distances, we observed an improvement in obstacles avoided when participants used the ioCane: over 19 runs using just a blind cane without the ioCane we recorded 13 hits (participant hit the object) and 6 misses (user detected and avoided the object) for an avoidance rate of 31.6%. With the ioCane, over 19 runs, we recorded 4 hits and 15 misses, for an avoidance rate of 78.9%, making the overall difference in obstacle avoidance a 47.3% improvement.

User	Without ioCane —— With ioCane			
	HIT	MISS	HIT	MISS
1	MH	L	–	LMH
2	LMH	H	H	LMH
3	LMH	LMH	LM	LMHH
4	LLMMH	H	H	LMMHH

Table 3: Results by user of obstacle course runs, with and without the ioCane. Obstacles marked by height: L=Low; M=Medium; H=High.

Table 3 shows a breakdown by user and obstacle height of all the recorded runs through the obstacle course. Average course completion times were 18.5 seconds and 26.4 seconds, without and with the ioCane system, respectively. The higher average time while using the ioCane may potentially be attributed to a number of factors, including unfamiliarity with the system and that concentration on feedback from the system may tend to slow the user down somewhat. As mentioned earlier, the average training time with blind canes is 100 hours, while our users had 30 minutes or less with our device. A longitudinal study may yield greater improvement.

We received useful feedback from all participants about the system. Helpful criticisms included making the attachment lighter, including an earbud for auditory feedback, including a panic button for emergencies, and an easier on/off switch. Since all participants opted to wear the phone around their neck, the haptic feedback did not help with the same immediacy as the tonal feedback. There was general agreement amongst users that corresponding the volume to the proximity of the object would be more useful than the haptic feedback (the louder the beep, the closer the object). However, had we tested the ioCane with the phone in the user's pocket, the vibrations may have been more apparent. One user wanted to explore the ioCane as a handheld device without the use of the cane (see Figure 7).The user stated that a handheld device might gain interest from elderly users who refused to adopt a cane but were suffering significant vision loss. This prompted us to conduct an informal test. We were able to attach the housing to the user's hand and have them walk around with it. Although the angles of the sensors were designed to be on a cane and not a hand, the concept proved feasible and would require only a minor redesign of the housing and sensor mounts, making it an intriguing area of pursuit for future work.

We also received positive feedback as all participants reported that they felt the ioCane was indeed helpful in avoiding obstacles. Several participants expressed that it was a 'great job' or that 'it was cool!'. Users also reported that they liked the tone/height correspondence, that it helped them maintain a straight path ('Before, I couldn't walk down the middle of a hallway', 'It's kind of cool because I can walk down the middle without uncertainty'), that the ioCane was 'really helpful' in detecting objects, and in general that the system would be useful for them while navigating ('If its not beeping then I know I'm in the right spot', 'just knowing that there is something there is great').

Due to differences in visual impairments and limited number of runs, we cannot say that this data is generalizable across the entire visually impaired population, yet the pilot test does offer significant encouragement for continued work with the ioCane. Obstacle avoidance increased by over 47% after less than 30 minutes of training time, which is .05% of the time for normal cane training.

Upon evaluating the production cost of the current system we found that the ioCane is 1/3 to 1/4 the price of comparable commercial systems, even when factoring in a Android phone. System components cost no more than $200 USD at retail pricing, while commercial competitors ranged from $800 to $1000 USD, and several Android phones are available in the US for under $60 USD. It should also be noted that in reviewing related work, we found no instances of any smart phone-compatible ultrasonic cane system conducting user testing with the target population, making our pilot study invaluable for our system and potentially for other researchers in the field.

FUTURE WORK

One of the primary advantages of the ioCane system is its plug-and-play integration with the Android OS, allowing the ioCane app to make use of available smart phone capabilities. We have identified several potential extensions in this vein that would make the ioCane even more useful as an ETA for the blind. We have begun work on one such addition: curb detection from a camera phone. Most Android phones have cameras, so we sought to use computer vision algorithms on camera input to detect objects of interest, effectively providing an additional layer of sensing ability to the system. Preliminary interviews indicated that detecting curbs was a common difficultly, so we developed an algorithm that runs with our app to detect curbs. The algorithm utilizes a two-phase approach that runs a Canny edge-detector through a Hough transform to detect horizontal lines that are likely to be curbs. Our early implementation of the algorithm gives voice prompts from the phone when a likely curb is detected. Although the implementation is complete, we have not yet had time to evaluate it. Should this approach prove useful, a variety of common-interest objects could be identified and integrated into our system. It should be noted that work has been done on recognizing zebra-crossings [23], but not from a cell phone camera and not including regular curbs.

CONCLUSION

The ioCane, a mobility aid for the blind, is the first system to integrate an ultrasonic sensor array with Android phones. Obstacle avoidance is achieved through haptic and audio feedback that correspond to the distance and height of an approaching object. We also present novel algorithms for dynamically determining the cane angle to the ground, estimating the canes location in space, and calculating the height of interfering objects based on sensor data and the user's height. By using common parts, the ioCane is both cheaper (by 1/3rd to 1/4th) and more extensible then existing ETAs. A user study with blind cane users revealed a 47.3% improvement in obstacle avoidance after only 30 minutes of training time, a fraction of the normal training given to blind cane users.

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