floorSight – Indoor navigation aid for the visually-impaired

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ABSTRACT

For those with vision impairment, navigating new areas can be arduous and frustrating. While GPS technologies continue to improve, providing turn-by-turn directions outdoors with great granularity, their helpfulness ends upon going indoors. This paper presents the design, implementation, and experimentation of the floorSight system, a system to help users maneuver in new indoor areas, providing navigation for those with visual-impairment through non-visual cues and feedback. An app utilizes uses Android application, sensor data and Bluetooth beacons to approximate an indoor positioning system (IPS). The floorSight uses vibrations and audial alerts to signal current location to the user, allowing them to maneuver through new environments with greater ease towards discrete destinations. Despite general difficulties in the developing IPS technology beyond a certain threshold of accuracy, the team in this implementation's potential impact on the process of navigating new indoor environments.

AUTHOR KEYWORDS

Bluetooth beacon; indoor localization; tactile and audial feedback; navigation system; ubicomp

ACM CLASSIFICATION KEYWORDS

H.1.2 User/Machine Systems; I.2.9 Robotics: Sensors; H.5.2 User Interfaces: Auditory (non-speech) feedback; E.1 Data Structures: Tables;

1. INTRODUCTION

For individuals who are visually impaired, the task of understanding the layout of new environments is a burdensome process. Difficulty with spatial navigation (e.g. navigating around obstacles, estimation of distance, noting landmarks) is a common theme for individuals with these disabilities, and a common situation that requires new forms of assistance [3]. This difficulty is reflected in a questionnaire conducted to determine the impact of sight-based disability when performing everyday activities (called the Impact of Vision Impairment or IVI). This survey, given to 115 individuals, revealed a significant amount on the degree that difficulty seeing impacts daily activities. On the 0-5 scale (with 0 being no difficulty and 5 indicating a total inability to perform the task), concerning getting around one's home the average score was 1.07, a significant difference from activities like: getting by outside the home (1.99), getting around while shopping (2.10), and going out to performances or sporting events (2.47). In fact, among those to whom the questionnaire was administered, 68% reported that it made day-to-day activities harder, 38% stating their disability caused them "a lot of difficulty" [7].

Unfortunately, because most current navigational technology would cost hundreds or even thousands of dollars, while also being somewhat complicated to use, individuals who are older or make average or below average income (the majority of visually impaired) are at a significant disadvantage. The team wants to address this autonomy-focused problem through developing a system to help users map the arrangement of new areas, providing a way for those with trouble seeing to maneuver even without external assistance. To do so, the scientists weighed the pros and cons of different modes of navigation to maximize convenience and accuracy while minimizing complexity, eventually landing on the premise of floorSight.

Most current individual-focused navigation systems can be divided into five groups: Sonar-based, camera-based, Infrared, GPS, and indoor navigation focused, each with specific benefits and drawbacks. By weighing the pros and cons of each, the team eventually decided to focus on an IPS (Indoor Positioning System) focused approach, as it would have the greatest impact on visually impaired people who, while required to "learn" the layouts of new locations, are frequently limited by the lengthy and inefficient process of memorization of individual landmarks in familiar locations.

2. RELATED PROJECTS

Multiple organizations have also attempted to analyze and address the issue of blind navigation in the past through multiple different means. Experiments utilizing this design concept have typically utilized at least one of the five navigational approaches mentioned above, with the primary goal being maximization of maneuvering precision.

One example of this is an Emergency Rescue Localization system (ERL), that integrates cameras and information extracted from a WLAN (wireless local area network) setup. This serves to map physical locations indoors (using the camera), to traceable localization coordinates from WLAN data. The resulting output of this interaction is then a matching between point image data and coordinate data derived from the WLAN information. This system is also supplemented by using GPS to receive any location information concerning the outside [2].

Another approach, in this case visual light communication (VLC)-based, utilizes a mobile device's accelerometer and image sensor in combination with LEDs as indicators. Similarly, to the ERL system, this method maps 2-dimensional data to a 3-dimensional coordinate system. Using a system of LED panels, with known coordinates, and a device's image sensor, with the team's algorithm deriving exact position from comparing the resulting picture of the panel to the previously known LED panel coordinates. This system (by including an accelerometer to uncover the resulting tilt of the image sensor/device) allowed the team to estimate phone decision with high accuracy [5].

In comparison, RFID (Radio Frequency Identification) devices, while originally used for either military or commercial uses, have also been converted for indoor localization use. RFID technology, which used radio waves to transmit the identity (and other information) of specific objects, has developed quite rapidly in recent years. Incorporating three main components: a tag (e.g. barcode, label), a reader (analyzing the data held in the tag), and a host computer, RFID indoor positioning systems can have readers activate as soon as tags enter their range, derive their exact location from signal strength and time of entry, and return it to the host computer. This process is naturally very useful in developing localization systems, while, like most others tending to be hybridized without one of the other localization modes, like GPS, to maximize efficiency [1].

A final method similarly uses observation of signal strength to determine position. The Talking Signs project installs infrared transmitters throughout the sample environment, each of which continuously emits digital speech stating what object lies at the transmitter's position. Under this system, any user holding a receiver can collect a signal, allowing them to decide the correct travelling direction by orienting the device to magnify signal strength. This system, developed specifically for visually impaired users, efficiently uses sound to compensate for the feedback limitations for this target audience [4]

Each of the processes researched had unique benefits, and most utilized more than one navigational method, the team adopted the same strategy for the development of the floorSight.

3. TECHNOLOGY

Scalability and ease of access was a large focus in how the team planned and developed the system. Whether floorSight would make a meaningful impact on indoor navigation was important, but for the impact to extend to the real world, it needed to be cheap and simple for any location to setup the infrastructure that would support someone who had the smartphone application. As a result, the team only used three technologies:

Figure 1. Bluetooth Low-Energy Proximity Beacon

Model: EMBC01

1. EMBC01 Low-Energy Bluetooth Beacons

The beacons chosen had several features that would help the system. First, each beacon has a battery life of months, which would be important in ease of maintaining an array of them in a building. Second, they are weatherproof, meaning that outdoor accessibility would not put them at risk. Finally, each beacon is extremely small, only ~40mm in diameter, meaning that placing them strategically throughout a building would not be challenging.

Figure 2: The device used for developing and testing was a Galaxy S7, the approach taken is not limited to this device

2. Galaxy S7 Android Smartphone

The second piece of technology required for the system was a smartphone, which the team chose to use the Galaxy S7 for no particularly discriminating reason.

This phone has use of a Bluetooth adapter, for communicating with Bluetooth devices such as the beacons, as well as an accelerometer and magnetometer, to be used jointly to determine heading information.

Figure 3: Bose Sound Sport Earbuds

3. Earbuds Compatible with Android Phone

The final technology used were Bose earbuds. Again, these were chosen simply that they met the criteria of being able to deliver audio feedback while connected to the Android smartphone. Any headphone system would work here.

4. METHOD

The team's approach to this project was to utilize the compass and Bluetooth sensors of a user's smart-phone in conjunction with a system of Bluetooth beacons (shown in Figure 1) to estimate the relative location of the users at a given time. By providing a rough triangulation of user positioning in relation to specific beacons, the system should provide feedback through vibration and audio alert, making users aware of the directions and distances of each beacon, and by extension their position in the room/building. This feedback will consistently provide a benchmark for users to estimate the location of specific rooms and devices without the need for complete spatial memorization. From the signal strength observed from the beacon sources, the smart-phone will attempt to determine whether it is in the proximity of a predefined zone. From here, the heading will be measured to determine when the user is correctly facing the correct direction to the next zone. By providing constant tactile and audio feedback through one's phone, the team wants the floorSight to function as a guide for the user, allowing the target user to have more day-to-day independence.

*Note: Finding the correct balance of distances for a zone is very important for two reasons. The first is the increased variance in RSSI value as the user gets farther from the beacon, and the second is the generalized nature of the heading– the larger a zone becomes, the more margin of error there is for the users' final location after following a given heading.

USER FEEDBACK

One of the main challenges for the floorSight system was to determine a way to provide non-visual feedback to the user. We need to communicate firstly if users are moving in the correct direction. While most navigation systems would depend on visual cues, our target audience limited us to non-visual signals.

To address this, the first idea to convert a potential visual signal to an audio statement/alert, saying "left" or "right". Instead the team focused on a more intuitive sort of feedback; the eventual system we implemented was a simple audio tone that, based on the specific signal, would play through the left earbud exclusively, the right exclusively, or both at the same time. This new feedback system was intended to replicate how a continuous sound-based detection system might intuitively operate.

The second feedback we had to provide is to indicate that a user had entered the next "zone" which would result in the corresponding target heading changing as well. In order to avoid adding more audio stimulus to the user, the team elected to use a simple haptic feedback with vibration-based indication to help the user determine zone changes. The device itself vibrates once to indicate a zone change, with a longer vibration to refer to arrival at their destination.

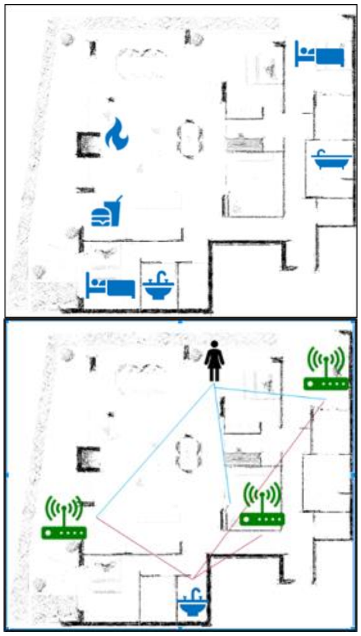


Figure 4: Diagram of original concept implementation which would attempt triangulation to determine localization, this

approach was scrapped in favor of discrete localization using beacons marking zones

SYSTEM DEVELOPMENT

The first goal in development was to set up a common starting point for the hypothetical user, marking this area with a Bluetooth beacon. After this the team converted the designated starting point to a “zone”, classified with a name and representative ranges of signal strength from the beacon, which were used to determine if the user is within its designated radius. Next, a destination zone is established through a similar process as with the starting point. To allow for a full route between the start point and the destination zone, additional zones were added in between the two, such that each zone is a straight path from one zone to the next, creating a series of straight paths to the final zone. The final step is to utilize the user’s current zone and the direction their smart-phone faces to determine the way to the subsequent zone. Each zone has a heading associated with it, which decides what path to follow next.

To elaborate on the process from the user’s point of view, the system begins with the user in a single initial zone, holding their device to feel vibrations and with headphones in to hear audio feedback. Their mobile device will vibrate to let the user know that they are within a certain radius of a beacon.

Upon vibration, the phone develops a heading that the user should follow to determine how to adjust their direction – heard through the corresponding headphone. If the user doesn’t need to adjust they will hear the signal through both ears simultaneously

The user should follow that heading with a moderate speed (a slightly slower gait than normal walking speed) - too fast and the devices knowledge will lag because the sensor readings are based on a moving average.

This heading is followed until phone vibrates again to inform the user that they entered the next zone and the sensor is calibrating the next heading. Lastly, user arrival to their destination is indicated through a three second vibration.

DATA MODELING

For the system, the team collected two main subsets of data, with the first being RSSI (Residual Signal Strength Indicator). When a Bluetooth beacon is activated, a smart-phone in discover mode should detect any Bluetooth signal, the corresponding MAC address, and signal strength from that MAC address.

The first step was to determine the nature of the relationship between distance and signal strength. To accomplish this, markers were set at fixed distances from a beacon (min: 1 ft, max: 60 ft) and took multiple strength readings at each. The team discovered from this data that the strength of radio frequency waves, like those used by Bluetooth were sporadic, with measurement of this data proving to be very noisy. The model counteracted this noise by employing a simple moving avg. over the most recent 5 samples collected at any time. The choice of 5 was made due to the inconsistent sample rate, derived from the time a device ends up taking to detect another device.

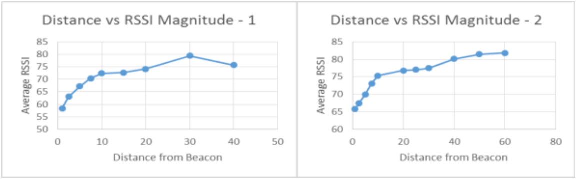
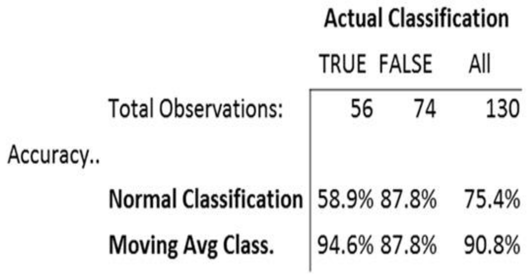


Figure 5: RSSI magnitudes measured at specific distances from the beacon

Experiments showed that signal strength and distance from the beacon source wasn’t consistent at all ranges (Figure 5). While readings showed semi-linear behavior within around 10 ft, after that the signal strength became far more inconsistent. From this the best way to determine localization would be by discretely classifying, based on signal strength, whether the device was in a fixed proximity of the beacon. This resulted in an approximate maximum radius of high accuracy being 10 ft.

When testing the sample classification of whether a device was within a zone based on signal strength, the team discovered that utilizing one beacon’s signal strength as a reference resulted in a large number of false positives (incorrectly detecting someone was in the zone) as shown in table 1. To increase precision of the model another beacon was added ~30 ft. from the first and determined the upper bound of the signal strength that the device would see from the second beacon when inside the initial zone. This constraint helped massively when detecting accuracy. Based off the observation of increased precision when adding more beacons, it was determined that including more beacons in the final model would be very helpful for determining zone position.



		Actual Classification		
		TRUE	FALSE	All
	Total Observations:	56	74	130
Accuracy..				
	Normal Classification	58.9%	87.8%	75.4%
	Moving Avg Class.	94.6%	87.8%	90.8%

Table 1. Zone Proximity Classification with and without moving average model

HEADING CLASSIFICATION

The second piece of data required for this implementation is the compass heading data, taken from the smart-phone accelerometer and magnetometer. Incorporating the data from these sensors makes it possible to approximate a heading even in an indoor setting. However, it should be noted that these values are much less consistent than they would be outdoors, which the researchers had to be aware of going forward.

In initial data observations, the group observed the raw bearing data was also extremely noisy. Once again, the team resorted to using a moving average to smooth the data. Even so, this new function differed:

1. Due to the much higher sampling rate of the smart-phone sensors, the researchers became able to produce the moving average to the previous 100 values observed instead of 5

2. Because of the nature of the data, ranging from -180° to 180°, inclusive.

The impact of the second change is best demonstrated in a situation when someone's bearing is in the range of +/- 170°-180°. In this scenario, the moving averages that spanned this area would approach zero, as both extremes were in the same direction, resulting in a flawed average. In response, the team modified the moving average to take the absolute values of the heading readings and using the sign of the original sum of those readings to determine the sign of the new moving average.

Finally, to get the classifications needed for the system, we'd need to, determine whether to turn left or right (if off heading) as efficiently as possible, based on both the current target heading and the direction the device is facing. For example, given a target heading of 160, and a current heading of -150, the signal should be for the user to turn left instead of right, to minimize the time spent adjusting (as shown in Diagram 1. By utilizing all the above, the floorSight system becomes capable of determining localization based off proximity to the Bluetooth beacons, in conjunction with heading correction based off device sensors and pre-determined target headings.

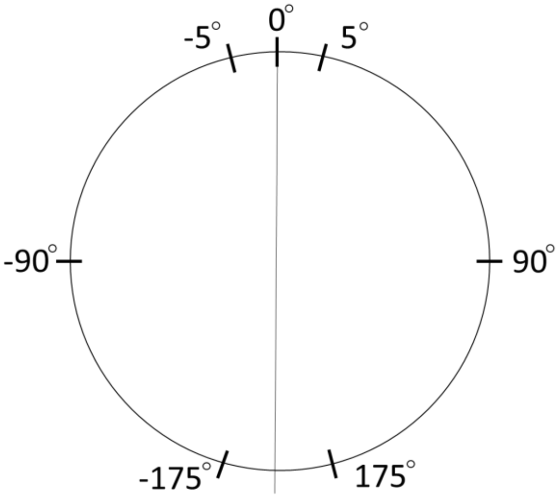


Diagram 2. Diagram representing the ranges of degree sensor values

5. USER STUDY

In setting up the user study for the floorSight system, the main priorities were to determine the effectivity of the specific feature-set and to explore other methods for non-visual indoor navigation. The setting for the user study is a subsection of the second floor of the Gates hall building at Cornell as seen in Figure 6.

Figure 6: Panorama of the User Test Location with rough labelling of beacon-zones

In setting up the experiment, the system utilized 3 Bluetooth beacons representing 3 proximity zones. The first beacon marks Zone A located at the elevator door (where the user starts), the second beacon marks Zone B at the corner and chair, and the third marks the destination door and Zone C. The aim was to represent a simple, yet realistic setting that would include hallways and a turn.

Figure 7: The final beacon can be seen on top of the sign to the bathroom

In the first several runs, volunteers to the study were first explained the goal of the study and given a high-level explanation of the system. After which, they were given basic instructions to find the destination door from the elevator while keeping their eyes covered. This was done to serve as a sort of control proxy, and each trial was video recorded. After the participants reached the destination, they were brought to the beginning to try again using the floorSight system. The basics of the system were explained to them, including what sort of feedbacks there were and general practices.

FINDINGS FROM PART I:

After explaining the general layout of the hallways and giving cues to the destination such as being the second door on the left, the team observed that all 4 users of the first study reached the destination in 37 seconds on average by using their hands to feel the wall as reference. The test then consisted of transferring them back to the start and giving them the floorSight system, then explaining its functionality before asking them to attempt it once more, following the vibration and audio cues.

For the first two users, they followed the audio cues intuitively, with appropriate vibration feedback at the turn, however were both led off course by the final heading information and never reached the destination. The cause of this inconsistency was determined to be the drop in heading sensor accuracy while the user was in motion. Based on this information the next two users were instructed to focus finding the correct heading at each zone, but to rely less on the audio signals when moving. This proved to be much more effective as both users reached the destination in 45 and 39 seconds respectively.

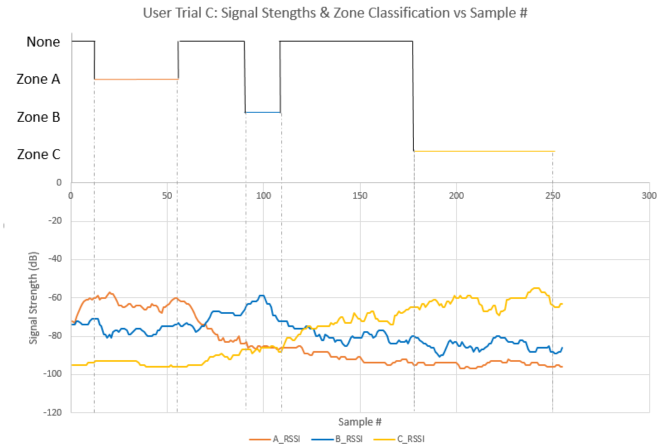


Figure 8: Graph displays the sensor data of the device used for user testing for the third user trial

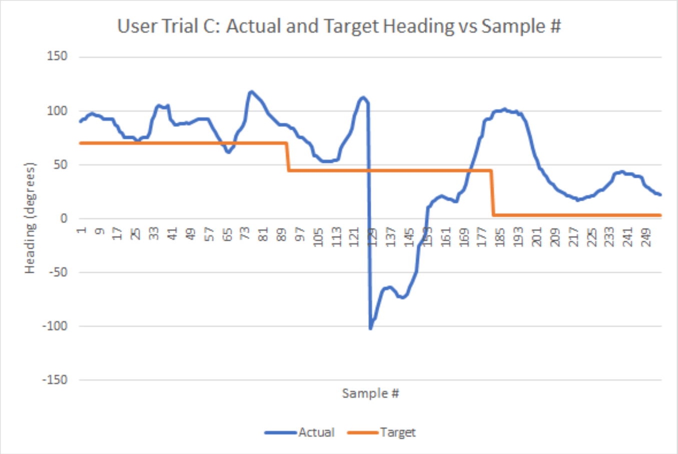


Figure 9: Graph displays heading sensor data from the floorSight device compared to target heading

Figure 6 shows the signal strengths, the respective zone classified by the model, and heading data observed by the device over the course of the trial. As Figure 6 shows, the zone classification is consistent with what the team would expect based on the signal strength data. In Figure 7 one can see the actual heading of the device deviated about the target heading and the user made corrective adjustments to remain "on-heading". While the floorSight system saw two successful runs, the risk of inconsistent heading data became clear.

ADJUSTMENTS:

Despite these different cues, the team continued to observe error prone trial runs. The team then moved to make two major changes. The first of which, that there would no longer be a control blind run to the destination, as it gave the participants a prior knowledge of the layout and the destination. Instead, they would use the floorSight system from the start, and would not be told where the destination would end up. This way, there would be no bias in how users acted upon feedback from the system (such as ignoring a directional cue because of prior knowledge of the area). The second major change was that instead of a constant audible feedback determined by the current heading and target heading, the users would be given a discrete instruction at each zone. The team observed from control runs where the participants would use the wall and other cues for guidance for nuances, and the hallway paths were straight anyway. For example, at the elevator door, the user would hear a single cue from their left ear, which was explained to be directing a 90 degree turn in that direction before continuing straight. Then upon entering the second zone, they would receive another beep, through the left ear to denote a left 90 degree turn. Finally, upon entering the destination zone, they would hear another left beep, where upon turning they would experience the prolonged vibration representing arriving at the destination.

FINDINGS FROM PART II:

After adjusting the format of the user study, the team then ran the experiment with 4 brand new volunteers who were introduced to the system, newly adjusted audio feedback and the ambiguous destination. Except for one, each user could locate the destination correctly in 37 seconds on average. The user in exception was unable to complete the course due to passing through zone B and not receiving classification until too late due to the speed of their walking a lagging sample rate. The final user also received a cue that the destination was on the left upon entering zone C early due to the classification model being adjusted for a faster walking speed.

These explorative user studies left the team with several strong takeaways. Firstly, heading data acquired from the phone in an indoor environment while moving are too inconsistent to use continuously for an effective navigation system. After observing the ability of users to locate the destination after given a high-level understanding by using the wall as reference, the team determined that a system that emphasized the reliable strength of determining zone proximity with some discrete directional cues would be optimal. The second was that users quickly found the nature of the audio cues to suggest direction change to be very intuitive, requiring very little assistance and quickly adjusting to feedback. Combining this with the last observation, the team found that providing discrete directional cues upon entering different zones along the way to the destination to yield much stronger and consistent results of successful navigation. An additional advantage to implementing this change is that the scalability of the system for when multiple paths are established using common beacons and paths.

Figure 10: User navigating the hallway without using vision or assistance

Figure 11: User arriving at the destination while using floorSight system, including earbuds

6. DISCUSSION

LIMITATIONS

As the team quickly observed, there were several limitations on the reliability of the information that could be gain through signal strength and heading data. For example, the original intention was to use several Bluetooth beacons situated throughout a building and then use the resulting signal strengths as a mapping to distance from each beacon and hen use that mapping to determine relative location within the building. After researching and observing the fickle nature of the radio frequency waves of Bluetooth, this was determined to be infeasible. While from the data discovery, the team could classify proximity to beacon (5 feet) with relative accuracy, it was still necessary to use multiple beacon signal strengths to avoid false classifications. The other limitation observed around proximity classification was that surrounding classification thresholds combined with walking speeds. As seen from the user study, if one were to “loosen” the threshold to accurately classify for a fast walking user, that model might easily give an early classification for a slow-paced walker.

The second major limitation met was the inconsistency of heading data indoors. While fairly accurate outdoors, when combining movement and indoor interference the data can easily be unreliable especially when attempting to attain a smaller granularity of attaining the direction from one beacon to another one a distance away.

With adjustments to both limitations, the most important limitation remains to be the battery draining nature of the floorSight application. Due to the nature of Bluetooth discovery, whenever a device is subject to continually searching for nearby signals it is incredibly demanding on the hardware. Should another party attempt to replicate the floorSight system, it would be necessary to determine a countermeasure or workaround for this to be a frequently used technology.

FUTURE WORK

In addition to limitations, the floorSight experiments also gave many positive signals of potential. Auditory signals through the left, right, or both ears proved to be as intuitive as the team had hoped, showing its potential in a more finalized product. Proximity classification showed promise assuming a moderate walking speed as well, and the vibration haptic feedback had the desired effect of giving the user a sense of rough localization.

The success of future work should place emphasis not on entirely replacing any method of navigation a visually impaired person may use, but supplementing where it falters. The evidence for this priority came from the switch from using continuous heading feedback to simple discrete instructions at turns and destinations, while allowing for other intuitions such as feeling a wall for reference worked well in tandem. While this new approach relieved the system of the burden of unreliable heading data, it was also tested in the context of hallway-like navigation where references such as a wall were constant. Any further work in this direction should seek to find a medium between these directional navigation approaches as discrete signals are scalable and reliable, but granular heading cues become more necessary in open layouts.

The team believes that next steps in optimizing this aspect of the system would be to explore use of the gyroscope and accelerometer on the phone to a further extent to attempt to classify steps and turning.

Another area or improvement would be to find a simple method and model for consistent determinations of signal strength ranges to use for classifying the proximity of certain zones. Through the experiment, this was done ad hoc by observing sensor data and using intuition, then hard coding the ranges. For a system to be scalable, it would be necessary for a non-tech savvy person to follow a simple procedure that would automatically generate the needed criteria.

Finally, while public buildings such as malls, offices and restaurants were the original foci of locations where floorSight to be impactful, they do show some drawbacks. Businesses may not, on their own initiative, take on the costs and efforts to establish floorSight beacons in their locations, considering the small population of visually impaired. It is from this intuition that the team would refocus the primary target locations for a floorSight system to be blind schools and universities, which would not only have the highest and most consistent need, but also the best opportunity to have a mutually beneficial relationship through development, testing and deployment.

Figure 12: Experimental logo for floorSight

7. CONCLUSION

This paper has now presented the team’s exploration of an early prototype of a system to facilitate indoor navigation for the visually-impaired. Not only has the following exploration outlined shortcomings in technologies that might be used for navigation, but it has also highlighted the potential for a lightweight system using a layout of Bluetooth beacons combined with proximity classification, as well as intuitive approaches for conveying navigational feedback through unobtrusive audio and vibration signals. The floorSight system contributes to the blind accessibility discussion by creating tangible results at a small scale, all while using a flexible and scalable approach. While there remains plenty of room for additional explorations in classification, edge case exploration and reliability, this paper presents a strong new platform for indoor accessibility for the visually-impaired with realistic deployment implications.

8. ACKNOWLEDGMENTS

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