GuideBelt: Bluetooth-based Indoor Navigation System for the Visually Impaired

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ABSTRACT
There is a lack of cheap indoor navigation systems tailored for the use of the visually impaired. This paper presents GuideBelt. GuideBelt utilizes Received Signal Strength Indicator (RSSI) from Bluetooth beacons to provide guidance to objects and places of interests in an indoor space with haptic feedback. We present the design and implementation of the GuideBelt, in the form of a functional prototype consisting of Bluetooth receivers, and haptic components. We also report an evaluation of the GuideBelt prototype, which is based on a study to test the ease of use, accuracy and performance; along with knowledge gained from interviewing test subjects. The evaluation shows that the users found the device easy to use; and with good accuracy.

Author Keywords
Indoor Navigation, Visually Impaired, Assistive Technology, Bluetooth

ACM Classification Keywords
K.4.2 [Computers and Society]: Social Issues - Assistive technologies for persons with disabilities

INTRODUCTION
According to the World Health Organisation there are about 26,350,000 visually impaired individuals in Europe[1]. Such people have great difficulty navigating the world both indoor and outdoor. GPS-based technologies have provided a great service to the visually impaired in terms of outdoor navigation. The reason for this is simple, the fact that it is cheap to implement and the typical modern smart device comes equipped with a GPS receiver; meaning that such outdoor navigation systems do not usually involve infrastructural overhaul to develop. It should however be stated that this does not mean that research is not being carried out to optimize outdoor navigation. But at least that there are cheap and significantly usable systems for outdoor navigation.

This is unfortunately not the case for indoor navigation. For years, guide dogs have been used considerably in alleviating navigation problems. However, it is expensive to train and maintain such dogs; in addition to the fact that there is a limit to how much a dog can understand of the human world. Therefore, there is a need to involve technology in this respect to address these issues. Based on our meetings with and observation of visually impaired persons, It is clear that there is a strong desire to have a cheap indoor navigation system, particularly for such use cases as being able to go out shopping alone.

Unfortunately, the technologies that have been used in solving this issue usually require dedicated hardware and other installations, which significantly increase the cost of such systems, for example the indoor navigation system proposed by Ran *et al.* [2]. The advent of beacon technology based on Bluetooth LE first by Apple and subsequent adoption on other smart devices, has led to the possibility of having a cheap technology for indoor navigation without the added cost of overhauling infrastructure, which is expensive.

The GuideBelt, which is the product of this research, is such a solution that takes advantage of these cheap Bluetooth beacons attached to places/objects of interest within an indoor space. The GuideBelt uses the Received Signal Strength Indicator (RSSI) to determine the direction of the object (whose symbolic location is the beacon) and consequently uses haptic feedback to draw the user's attention to the direction of its location.

This paper is comprised of a detailed enumeration of the works that have been carried out in the creation of indoor navigation system relevant to the visually impaired. A detailed description of the process of making the design decisions is also documented as this provides a crucial understanding of the rationale behind its design.

A description of the design and implementation of the GuideBelt is also given; after which the documentation of the evaluation process captures how the system was tested for accuracy, performance, usability and feasibility of practical use. Based on the evaluation of the GuideBelt we provide insights about the system and what can be improved.

RELATED WORK
There has been considerable research in the development of navigation systems tailored for the use of the visually impaired. Belotti et al. [3] in their solution used RFID technology and argue that their research direction is to proceed with the implementation using Bluetooth technology. The problem with their solution is that it is tailored towards guidance only for an exhibition and not general indoor use.

The solution of Galatas et al. [4], eyeDog, involved the creation and use of a guide robot. Unfortunately, this solution is cumbersome (as it means the visually impaired user has to have a huge metallic robot with him/her at all times). In addition, this solution could lead to excess cognitive load as defined by Marshall and Tennent [5], since the user has to pay attention to not only where he/she is going, but also how the robot is faring, for example when moving through a crowd of people. Shoval et al. [6] proposed the GuideCane. This system uses ultrasonic sensors to help the visually impaired person to navigate around. However, this solution does not actually provide navigation to objects/places, but rather focuses on being able to use the GuideCane to avoid obstacles in the path of the user.

Drishti developed by Ran et al. [2] is based on ultrasound positioning. It however has the problem that it is heavy (as it requires carrying a wearable computer in combination with other devices) and requires expensive dedicated infrastructure for indoor navigation.

ActiveBelt by Tsakuda & Yasumura [7], which inspired the development of the GuideBelt also provided directional information with haptic feedback. However in the case of the ActiveBelt, it was not tailored specifically for the use of the visually impaired. Another important difference is that the ActiveBelt utilized geomagnetic and acceleration sensors for such directional guidance; while ours uses RSSI from Bluetooth beacons.

Erp et al. [8] used a vibro-tactile waist belt (similar to the GuideBelt) to solve the problem of navigation under conditions of not being able to see (including under dense smoke and being visually impaired). However, their solution is for outdoor navigation (and also utilizes GPS).

Another wearable and tactile navigation solution developed by Berning et al [9] is called ProximityHat, which translated ultrasonic signals to tactile pressure on a hat. The problem with this solution is that an evaluation resulted in several collisions amongst the ultrasonic sensors leading to poor accuracy in terms of the direction.

The indoor navigation system developed by Ivanov [10] used RFID and NFC technologies with audio feedback to provide guidance for the visually impaired. Ivanov however reports considerable differences in the arrival times to destination in his evaluation, which indicates its poor usability. Vi-Navi by Mehta et al. [11] works using infrared. This system is however expensive as it requires the installation of infrared transmitters in the building as well as a server; which increases infrastructure cost; which makes our solution much cheaper. Our solution is cheaper as there is no need to install a server; the only things that need to be put in place are Bluetooth beacons which are cheap.

In summary, the GuideBelt is a solution that is cheap, ergonomic, accurate, and solves the problem of indoor navigation for the visually impaired in a novel way.

ITERATIVE DESIGN

It is important to note that the GuideBelt prototype developed and evaluated for this paper is an early prototype comprising of phones (to simulate Bluetooth receivers with vibration capability). The reason for this decision is take the focus away from the nitty-gritty of electronics to focusing on the actual design, and development of the core idea; which is the design of an indoor navigation system based on received Bluetooth signal analysis.

In the development of the GuideBelt, we tried several approaches through which we came to understand the possibilities and limitations of using Bluetooth beacon technology; and which consequently informed the design and implementation of the GuideBelt. These approaches are therefore associated with iterations of design.

In order to establish the direction a person is facing we identified that it was necessary to have two devices. One in the front and one in the back. Otherwise, despite knowing the signal strength we cannot say which direction the user is facing. This led to the decision to use a secondary receiver of Bluetooth signal. The idea therefore was to use a smart device for computation and as a front receiver. The secondary receiver was placed on the back of the user; and because of the occlusion of signal there is always a considerable difference between the signal received by the receiver facing the Bluetooth beacon (signal source) and signal received by the device facing away from the Bluetooth beacon. Based on this, the decision was to construct a wearable device that could serve the function of the secondary receiver and which could be strapped to the user's back.

Based on this decision we found it instructive to carry out tests of the RSSI, to understand and quantify the effects of occlusion on the signal strength. The setup of this experiment required the development of an Android application that would allow for the collection and output of RSSI. The following steps were then followed:

- Measure a distance of exactly one meter away from the Bluetooth beacon.
- Place one smart phone (which has the Android application installed on it) on the back of the user and the other phone (which has the same application installed on it) in front of the user. It should be made clear that for all tests the standard Android phone (Nexus 5) was used. It was important to ensure that the hardware is the same, so as to remove the effect of hardware differences.
- Run the application on the phones

- The application that we developed keeps a log of the RSSI on both phones.

This experiment was repeated for the distances 3m, 5m, and 7m away from the beacon (signal source). Due to the fluctuating nature of the signals; we decided to present the median RSSI in 5 seconds for the various distances as shown in Table 1.

Distance from Beacon	RSSI (facing beacon)	RSSI (Turned away from beacon)
1 m	-67 dB	-71 dB
3 m	-76 dB	-87 dB
5 m	-79 dB	-89 dB
7 m	-83 dB	-94 dB

Table 1: Observation from an experiment on the effect of occlusion on RSSI. It shows that there is always a considerable difference in the signals between that on the phone facing the beacon and that received by the phone facing away from the beacon.

The observations we made from the experiment are therefore the following:

- The Bluetooth signal from beacons fluctuates even when the receiver is standing in one position.
- A confirmation of our hypothesis (that there is always a considerable difference between the RSSI of the receiver in the front and that on the receiver on the back, due to occlusion).

The fluctuating nature of the Bluetooth signals revealed to us that there is a need to collect time series of RSSI which we can use for analysis.

Based on this understanding we built a prototype which uses two phones (one held in the front of the body and the other placed on the back). However, the accuracy that we recorded when we implemented the prototype was too poor (the method could only narrow down the direction to 120 degrees as can be seen from Figure 1).

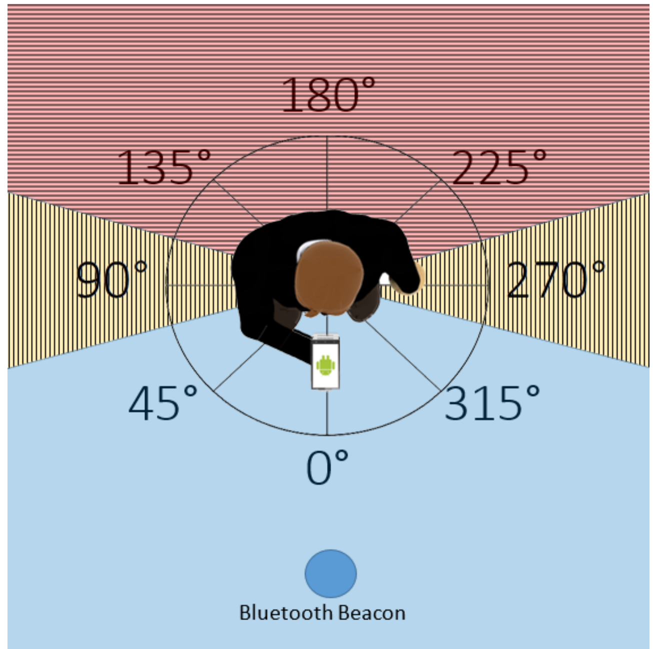

Figure 1: The plain part captures the area of possible direction (120°) of the beacon. The area with vertical stripes shows where considerable signal is received, but that is not enough to warrant it being the direction of the beacon. The part with the horizontal stripes captures the area where the signal is really poor.

This was determined by an experiment we conducted. In this experiment the participant starts by facing the beacon at 0°. Then he moves clockwise by steps of 45° until he returns to the initial position at 360°. Our observations from the experiment were:

- When the participant starts to pass 120° mark, the signal strength starts to decrease (from an average of -65dB to an average of -80dB) , as he progressively faces way from the beacon, as can be seen from Figure2.
- When the participant reaches the 240 mark, the signal strength starts to increase again as he progressively begins to face the beacon again.

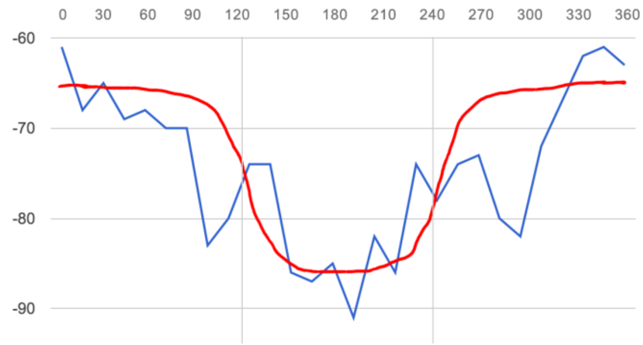

Figure 2: Graph showing the RSSI log of the rotation from the conducted experiment. As can be the signal strength begins starts to reduce drastically from 120° and goes to a trough and begins to rise significantly again from 240 °, considering a margin of error of 10 °.

In order to improve the accuracy, we increased the number of receivers on the back to two. One on the right side of the body and the other on the left side. Despite the fact that the accuracy increased, it was still not sufficient as it only narrowed the angle to 100 degrees, confirmed by the same type of experiment.

However, this gave us an interesting insight, that increasing the number of devices increases the accuracy of the system. Therefore, we developed a system that utilizes 8 devices, strapped around the waist like a belt (Figure 3). Hence each device would cover up to 45 °, making a total of 360 degrees (Figure 4). This is in fact the GuideBelt. The reason for choosing the number of devices to be 8 is to capture the 8 principal navigation points on a compass (North, South, East, West, North-East, North-West, South-East, South-West). The advantage of having it as a wearable belt, is that it provides greater stability, since all the receivers are held firmly in place by the belt. Furthermore, it is placed lower on the body to reduce the effect of occlusion by the hands on the on the sides (phones 3 and 7 from Figure 3)

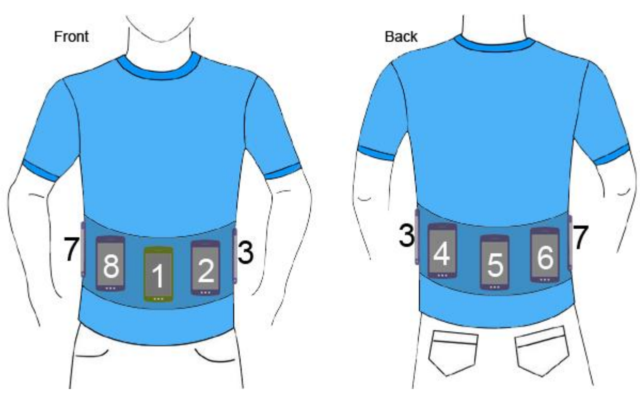

Figure 3: Design of the GuideBelt. There are 3 phones on the front of the body (1,2,8), three on the back (4,5,6) and one on each of the side of the body (3 and 7). Phone number 1 acts as the coordinator, while phones 2-8 are the coordinated devices.

The phone number 1 from Figure 3 acts as a Coordinator (Server), while the other 7 phones act coordinated devices (clients). The Coordinator has some responsibilities

- It notifies the other phones, which Bluetooth beacon (symbolically meaning the target location) to lock on and receive signals from.
- In fact, apart from its added functionality as a coordinator it does exactly the same thing as the coordinated phones.
- It computes and decides which phone (potentially its self) is in the right direction to the beacon.

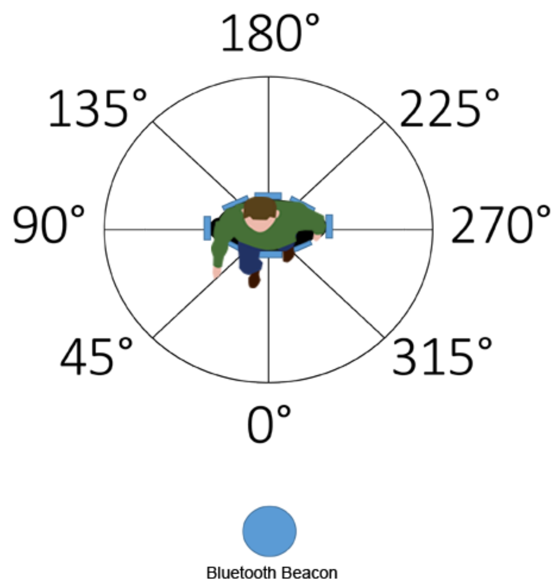

Figure 4: Relationship between the phones on the GuideBelt. It shows that the phones cover 45° each around the user.

The coordinated devices (clients) are 7 in number. Each phone (including the Coordinator) has a relation to the one directly opposite it as shown in Figure 3 (hence the phone at 90 ° and the phone at 270° form a related pair). The phone at 135° forms a related pair with the phone at 315 °. The idea is that if a phone is facing the beacon, then it means that the one directly opposite it (its related phone) is facing away from the beacon. For example, from Figure 4 it can be seen that the beacon at 0 degrees is facing the beacon while the one directly opposite it (the one at 180 °) is facing away from the beacon. As a result of occlusion; it means that the device facing away from the beacon would receive the lowest RSSI of all the phones on the GuideBelt. Therefore, if the device facing away from the beacon can be deduced in this way, it means that the direction of the beacon can be defined as being within 45 ° of the angle of the phone that is directly opposite this phone (in Figure 4 corresponding to the device at 0 °).

Once the direction has been decided, the Coordinator (Server) phone commands the appropriate phone to vibrate as an indication to the user of which direction he/she should be moving towards.

GUIDEBELT IMPLEMENTATION

The setup of the system, means having Bluetooth beacons attached to places of interest, like toilets, elevators, etc. These beacons are therefore symbolic locations for the places/objects of interest. The idea is that the user, utilising the GuideBelt's Coordinator (server) phone would select the place he/she would like to go and then start moving in that direction. The GuideBelt then uses the RSSI on the different phones on the belt, and haptic (vibrational) feedback to provide guidance to the location. The architecture and technical details of the GuideBelt are described in this section.

Bluetooth Beacons

These are placed on the objects/places that they are supposed to represent symbolically. They are kept constantly on, such that they are always transmitting their RSSI. A Bluetooth beacon transmits a UUID (Uniquely Identified ID), Major and Minor values, as well as the RSSI. However, in the case of the GuideBelt we are more concerned with the UUID and the RSSI. The UUID is a way to uniquely identify each beacon as a symbolic location. The RSSI is what is used by the application to calculate and determine Bluetooth beacon's direction.

The GuideBelt

The GuideBelt is composed of eight smart phones). The phones are arranged around the belt in fixed positions as defined in the design. The phones that were used were all Nexus 5 devices running Android 6.0 (Quad-core 2.3 GHz , Bluetooth v4.0-A2DP, 2 GB RAM).

Figure 5: The GuideBelt prototype, built using 8 phones (Nexus 5), arranged in fixed and precise positions.

Android Applications

Two Android applications were developed (as can be seen from Figure 6). The first one is for the Coordinator phone and the other application is for the other phones. The other phones simply need to be able to send the RSSI of the beacon to the Coordinator phone; to compute and analyze the direction of the beacon based on the RSSI.

The Android application on the Coordinator is therefore responsible for merging all RSSI (received every 4 seconds) from the different phones , sorting them and determining the direction of the beacon as described in the design

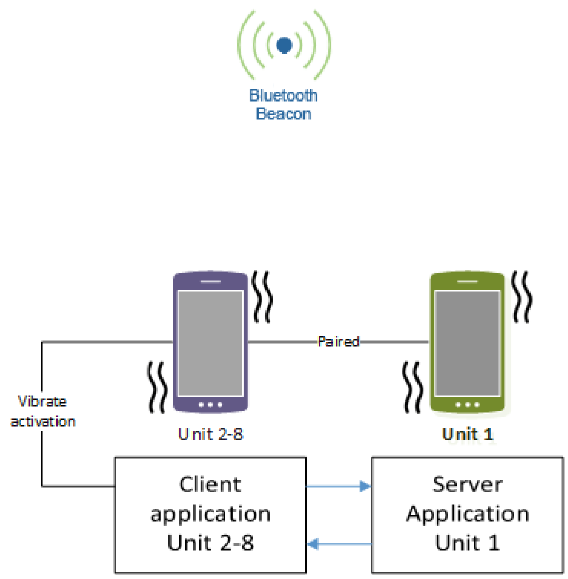

Figure 6: Architecture of the GuideBelt. The Coordinator (server) phone has its own Android application, while the coordinated (client) devices have their own Android application

EVALUATION AND RESULTS

The usability of the system depends on the accuracy and the performance in terms of how long it takes to find the target. Therefore an evaluation was carried out to scientifically quantify and define these two qualities. The evaluation was carried out in two phases. The first was a pilot study to measure the accuracy of the system. The second phase of the experiment involved 8 volunteer visually-impaired participants and was used to test a hypothesis. The hypothesis being that the GuideBelt working with 8 phones would have greater accuracy and hence performance than a 4-phone version (specifically designed for the evaluation as shown in Figure 7).

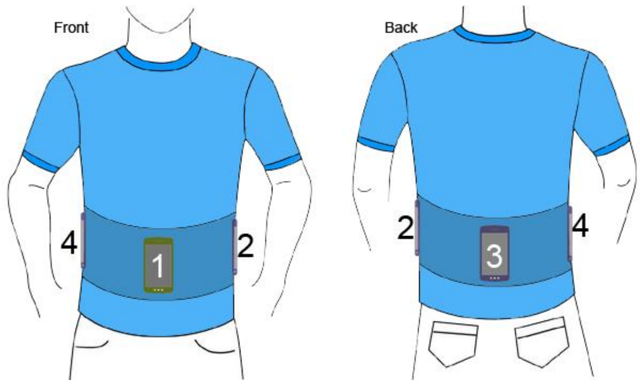

Figure 7: The design of a 4-phone version of the GuideBelt build and used for the experiment. It captures the four cardinal directions (North, South, East, West). There is one phone on the front (which acts as the coordinator), one on the left, one on the right and another on the back.

PHASE 1: PILOT STUDY

This involved measuring the accuracy of the system. Accuracy in this context means that the right phone vibrates in a situation in which it should be the one to vibrate (as defined in the design). Therefore, the experiment illustrated in Figure 8 was designed to allow for such a test.

From the figure it can be seen that there are 8 positions in total (0, 45, 90, 135, 180, 225, 270, 315) at which the test participant (with the GuideBelt strapped on) stood. The eight different positions (numbered 1-8 in the figure) with the phones represented by circles can be seen from the figure. At each position, the phone that should vibrate by virtue of it being the one in the direction of the beacon (in the center of the diagram) is represented by a tick.

A person stood at the different positions with his orientation identical to the ones shown in the diagram; and the phones that vibrated were noted down. This was repeated twice, making a total of three times. For the three trials (in positions (1,2,3,4,7,8) the right phones vibrated always. For positions (5 and 6) however, the wrong phones (with cross marks, as shown in the figure) vibrated in all three trials.

A possible source of error that could be responsible for this is signal reflection, due to the proximity (less than 1 meter) of the positions 5 and 6 to a wall during the experiment.

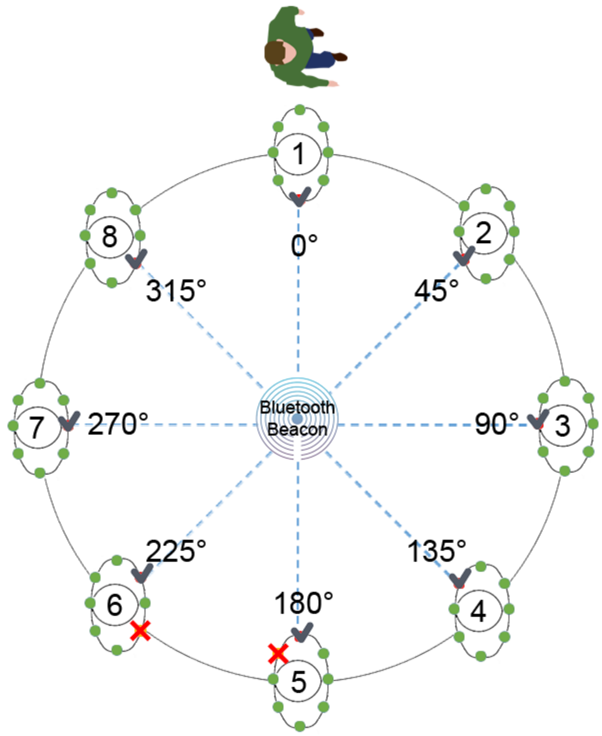

Figure 8: Setup of the accuracy test conducted as part of the pilot study. The expected phones vibrated at positions (1,2,3,4,7,8). The wrong phones vibrated at positions 5 and 6.

PHASE 2 : EXPERIMENT

In the second phase of the evaluation, the performance of the GuideBelt was measured by having visually impaired participants utilize it in an experimental setting. The experiment entailed measuring the time taken for the GuideBelt (which uses 8 devices) to find an object in comparison to the time taken for the 4-phone version to find the same object under the same conditions.

Participants

Eight blind volunteer participants (1 female and 7 males) were recruited in collaboration with the Instituttet for Blinde og Svagsynede (Institute for the Blind and the Visually Impaired). The ages of the participants ranged from 18-58 years (mean = 37.5, standard deviation=15.7). All the participants had no prior experience of the system. All of the participants however had prior experience with vibration as feedback by using phones. During the experiment the participants were allowed to use their guide canes; to make them feel more at ease about obstacles during the experiment.

Setup

An equilateral triangle with sides of size 5m was drawn on the floor (Figure 10), and the three vertices of the triangle were marked with tape as shown in Figure 9. The vertices were labeled as A, B and C. For each test, a chair with a beacon strapped to it is placed on one of the vertices and the participant is placed at another vertex 5m away.

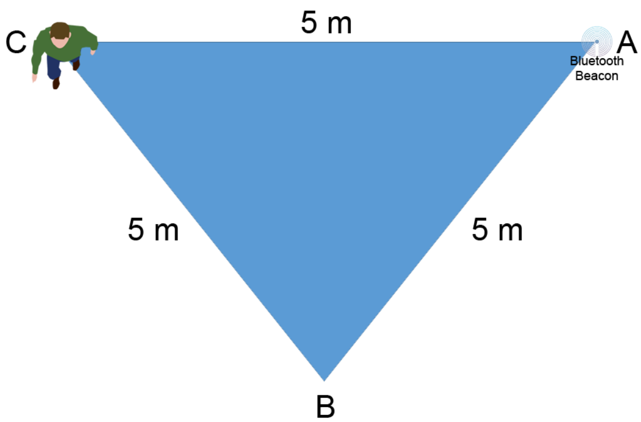

Figure 9: Conceptual depiction of the setup of the experiment. The Bluetooth beacon is placed at a vertex (A in this case), and the participant stands at another vertex 5m away (vertex C).

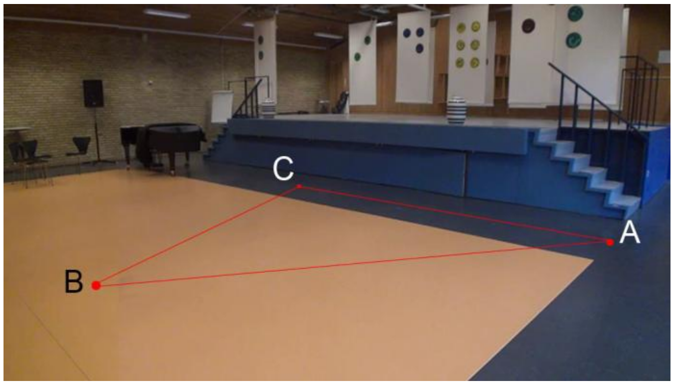

Figure 10: The actual setup for the experiment. Three vertices of an equilateral triangle served as reference points during the experiment.

Procedure

Each participant was evaluated separately and individually. For each of the participants (while helping them put on the GuideBelt), an explanation of the experiment was given for a clearer understanding of what they were expected to do. Therefore, the experiment began with a training session. The training experiment involved the participants finding the target twice using guidance only from the GuideBelt based exactly on the setup.

For each participant three tests were carried out using the 8-phone version and also three tests for the 4-phone version.

To ensure counter-balancing we labeled the participants based on their number of participation- even numbered and odd numbered participants. The placement of the beacon to be found and the starting positions of the participants were defined by these labels. Therefore, odd numbered participants started by standing at point A (with the beacon placed at point B), then from point B (with the beacon at point C) and finally from C (with the beacon at A), in the case of the 4-phone version (refer to Figure 9). When done with that, the odd-numbered participants then moved to the 8-phone version. In the 8-phone version, the odd-numbered participants went from C-A, then A-B, and B-C. The even numbered participants did the reverse, i.e., they started with the 8-phone version (and went in the reverse order with that of the 8-phone version of the trial of the odd-numbered participants) (i.e. A-B, B-C, and C-A). For the 4-phone version they went also in the reverse order (of that for the odd-numbered participants), i.e. (C-A, A-B, then B-C).

The significance of this was to reduce the learning and order effects. Also to ensure that the participants did not know where they were at each point, we used noise-cancelling head-gear, while moving them to the starting position, after disorienting them by spinning them around randomly. This ensured randomization for the participants, since they did not know at which position they were at each starting point.

After the experiments, the participants provided additional feedback through (a questionnaire and interview). However, to make it easier for the visually-impaired participants, the questions on the questionnaire were read out to them and we recorded their responses.

We categorized the statements in the questionnaire into three groups: usability, learnability and effort. The participants had to provide a grade for each of the statements from 0-9 (on the scale to which they disagree or agree with the statement respectively. The significance of using this grading was to allow us to quantify their feedback. In order to create open-ended questions (to generate feedback to be used for qualitative analysis), the statements in the questionnaire were converted to questions by introducing "why".

RESULTS AND ANALYSIS

The results that were gathered from the experiments and the questionnaire/interviews were collated and analyzed. Two types of analyses were performed: quantitative and qualitative.

Quantitative Analysis

The data from the experiment for the 8 participants is shown in Table 2. An inferential statistical test was carried out on the data. As the data collected is within group and also because each participant was tested with the 8-phone and 4-phone version, the t-test with paired (dependent) samples (comparing means) was used.

The Null Hypothesis (H0) is : there is no difference between the time taken for the 4-phone version and that of the 8-phone version of the GuideBelt to find the target.

The Alternative Hypothesis (H1) is: the 8-phone version takes less time to find a target than the 4-phone version. The result of the test is encapsulated in Table 3. As can be seen from the table the p-value is 0.49803 for a t critical value of 5%. Hence, even though there is a slight difference in the means (with the 8-phone version achieving better performance), the result is not statistically significant; and the null hypothesis remains.

	8-phone version			4-phone version		
	A-B	B-C	C-A	B-C	C-A	A-B
1	66,60	39,83	15,84	108,65	56,19	26,96
2	58,19	59,26	40,87	41,38	37,71	20,81
3	30,50	34,70	32,86	32,43	10,90	30,41
4	49,80	32,93	17,76	53,17	48,40	59,25
5	65,50	26,68	31,28	78,33	54,12	63,53
6	36,50	31,61	22,47	37,65	10,69	74,79
7	9,99	54,30	49,81	11,75	16,04	44,40
8	15,06	35,45	32,55	14,69	12,06	25,65

Table 2: The results of the time recorded for the 6 tests for the 8 participants. The first 3 columns are for the times recorded for the 8-phone version and the remaining columns are those recorded for the 4-phone version of the GuideBelt during the experiment.

Sources of error

Despite the fact that the results are not statistically significant, this can be attributed to several factors. First of all, the distance between the test participant and the target is too small (5m) to get a significant difference between the times recorded for the 8-phone version to that of the 4-phone version. This is in the sense, that if the distance was say 10m, then the superior accuracy of the 8-phone version would have shown itself more clearly, since the area to cover is greater. Secondly, some of the users rotated too often during the tests, which increased the number of vibrations they get and which consequently caused confusion. This therefore increased the overall time taken to find the target especially for the 8-phone version.

From observation during the tests, some of the users did not rotate to precisely the right angle (of the phone that vibrated) before starting to move. This was especially more so for the 8-phone version, which increased the time taken and recorded.

Furthermore, two of the participants complained that they had too many clothes on during the tests, such that it was more difficult for them to determine exactly which phone was vibrating. This increased the time it took for them to find the target. They said that this was mostly the case for the 8-phone version, because the phones are closer together in that version.

Comparing Means [Paired two-sample t-test]			
Descriptive Statistics			
VAR	*Sample size*	*Mean*	*Variance*
8 phones	8.00	38.6325	102.15402
4 phones	8.00	38.67375	327.50954
Summary			
Degrees Of Freedom	7.00	*Hypothesized Mean Difference*	0.E+0
Test Statistics	0.00512	*Pooled Variance*	214.83178
One-tailed distribution			
p-level	0.49803	*t Critical Value (5%)*	1.89458
Pearson Correlation Coefficient	-0.24642		

Table 3: **Results of statistical analysis of data reflecting the descriptive statistics as well as outcome of a t-test. The 8-phone version performed slightly better than the 4-phone version as per the means. However, a t-test with paired (dependent) samples (comparing means), shows that the difference is not statistically significant.**

Qualitative Analysis

The data gathered from the questionnaire was also analyzed to determine the usability, learnability of the system as well as how much effort it took to use it. As mentioned previously, the statements on the questionnaire, that the participants had to complete were graded and categorized into three groups: learnability usability and effort.

Based on this data the chart in Figure 11 was drawn. As can be seen from the chart, the system, based on the feedback of the participants has high usability and learnability. Furthermore, according to the participants, the system required little effort to use.

Moreover, since we asked them open ended questions as part of a post-experiment interview, the participants provided insight into the reasons for choosing the grades for the statements of the questionnaire. These feedback is therefore now summarized and presented.

Two of the participants attributed the usability of the system to the positioning of the GuideBelt on the body, saying that it made it easier to use in combination with the

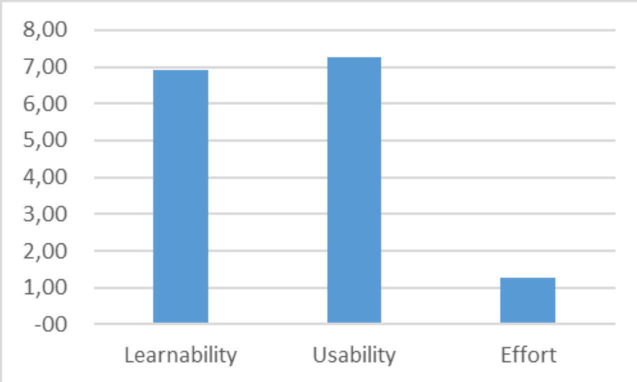

Figure 11: A graph visualizing the participants' feedback on the learnability, usability and effort (required) for the system. According to them, the system is easy to learn, and with high usability. They also think that it requires little effort to use.

guide cane, since it was not in the way. Out of the eight participants, seven reported that the frequency of vibrations was optimal. In fact, two of the participants made it clear that if the frequency of vibration was any higher, it would make the system confusing to use.

In terms of learnability, a participant commented that he thought that the GuideBelt was easy to learn , because it is in his own word "intuitive".

Furthermore, the participants gave reasons for why they thought the system required little effort, mostly attributed to the use of vibration feedback. When asked which feedback type they preferred to use with the GuideBelt (vibration or sound), 7 out of 8 of the participants argued for vibration (see Figure 12). The primary argument being that in noisy environments, it might be difficult to follow sound feedback. Secondly, a participant argued that he preferred vibration because unlike sound, he does not have the problem of dividing his attention between feedback for the system and that of the sounds in the surroundings.

A participant made it clear that she would appreciate to have a system that could easily be concealed and which did not attract too much attention during use. It should however be reiterated that the version of the GuideBelt used for the evaluation is an early prototype; and the future work to be done on the GuideBelt would make it more concealable, since components that will be used as replacement for the phones are not as big as the phones that were used in the prototype.

Another participant mentioned that he would like to have the system integrated with voice input; in the sense that a user can provide voice commands like "TOILET", which would consequently make the GuideBelt start helping him/her to the toilet in the indoor space.

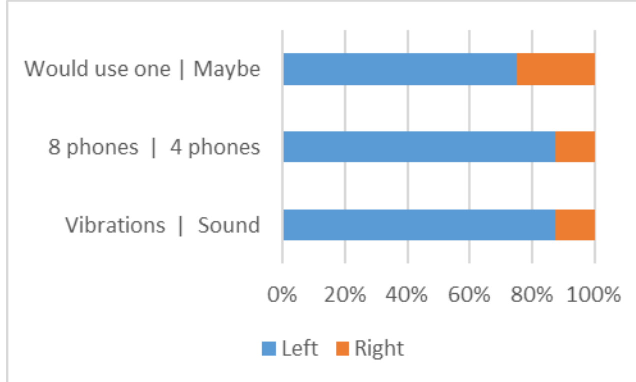

Figure 12: **Feedback of the participants regarding their experience of the system. 75% say that they would use such a system if it was available. 7 of the participants preferred the 8-phone version to the 4-phone version due to increased accuracy; and 7 also all preferred vibration over sound as feedback modality.**

DISCUSSION AND FUTURE WORK

The GuideBelt as it is now is limited by the range of Bluetooth meaning that it can only guide to objects that are 10m away. To make the system more usable for real life, it is important to be able to increase this range. Therefore, a research direction would be the creation of a GuideBelt that can coordinate between multiple beacons, via a path finding algorithm that can coordinate between different beacons to find a target that is more than 10m away. Knowledge gained from this work is useful for this, particularly the understanding of signal fluctuation and how time-series of RSSI can be used to make estimates of direction and position.

Furthermore, the accuracy of the GuideBelt can be improved by the use of a statistical filter such as the Extended Kalman Filter to remove noise from collected RSSI, hence minimizing the variance of the estimation error as used by Kotanen et al. [12].

Another issue that became apparent during the evaluation, is that sometimes while a user is turning to the right direction, the GuideBelt vibrates again, since it is modelled to vibrate after every 4 seconds, causing confusion for the user. To solve this problem, it is important for the GuideBelt to be able to detect movements (such as rotation). Therefore, we anticipate exploring the potential of augmenting the GuideBelt with accelerometers and gyroscopes to not only solve the problem of vibration during rotation; but also to improve the accuracy of the system.

Based on the feedback of a participant from the evaluation regarding the possibility of customizable feedback multi-modality (sound, vibration and a combination of the two), we anticipate research to be carried out in addressing this within the scope of Human Computer Interaction (HCI) for the visually impaired.

CONCLUSION

We presented the GuideBelt, a navigation system that works by processing Bluetooth signals and providing feedback by vibrations. Based on an evaluation of the prototype the usability, learnability and the fact that it requires low effort were established. However, it could not be proven with statistical significance that the 8-phone version takes less time than the 4-phone version; due to sources of error in the experimental setup.

The implementation of the GuideBelt that has been the focus of this work is an early prototype, which uses phones to simulate the Bluetooth receivers (coupled with a vibration modules). This was to allow us to focus on the focus to development of the algorithm rather than electronics. Therefore, the direction of this research is towards the implementation of the system with the actual technology necessary meaning with assembled electronic components (including Bluetooth modules and vibrators).

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REFERENCES

1. Euro Blind. (2015). Euro Blind. Retrieved 3 September, 2015,fromhttp://www.euroblind.org/resources/information/. In-text citation: (Euroblindorg, 2015)

2. Ran, L., Helal, S. and Moore, S. (2004). Drishti: an integrated indoor/outdoor blind navigation system and service. Proceedings of the Second IEEE Annual Conference on Pervasive Computing and Communications, 2004.

3. Bellotti, F., Berta, R., De Gloria, A., & Margarone, M. (2006). Guiding visually impaired people in the exhibition. Mobile Guide, 6, 1-6.

4. Galatas, G., McMurrough, C., Mariottini, G. L., & Makedon, F. (2011, May). eyeDog: an assistive-guide robot for the visually impaired. In Proceedings of the 4th International Conference on Pervasive Technologies Related to Assistive Environments (p. 58). ACM

5. Marshall, J. & Tennent, P. (2013). Mobile interaction does not exist. In CHI '13 Extended Abstracts on Human Factors in Computing Systems (CHI EA '13). ACM, New York, NY, USA, 2069-2078 DOI=10.1145/2468356.2468725 http://doi.acm.org/10.1145/2468356.2468725

6. Shoval, S., Ulrich, I., & Borenstein, J. (2003). NavBelt and the Guide-Cane [obstacle-avoidance systems for the blind and visually impaired]. *Robotics & Automation Magazine, IEEE*, *10*(1), 9-20.

7. Tsukada, K., & Yasumura, M. (2004). Activebelt: Belt-type wearable tactile display for directional navigation. In *UbiComp 2004: Ubiquitous Computing* (pp. 384-399). Springer Berlin Heidelberg.

8. Van Erp, J. B., Van Veen, H. A., Jansen, C., & Dobbins, T. (2005). Waypoint navigation with a vibrotactile waist belt. *ACM Transactions on Applied Perception (TAP)*, *2*(2), 106-117.

9 Berning, M., Braun, F., Riedel, T., & Beigl, M. (2015, September). ProximityHat: a head-worn system for subtle sensory augmentation with tactile stimulation. In *Proceedings of the 2015 ACM International Symposium on Wearable Computers* (pp. 31-38). ACM.

10. Ivanov, R. (2010, June). Indoor navigation system for visually impaired. In*Proceedings of the 11th International Conference on Computer Systems and Technologies and Workshop for PhD Students in Computing on International Conference on Computer Systems and Technologies* (pp. 143-149). ACM.

11. Mehta, P., Kant, P., Shah, P., & Roy, A. K. (2011, June). VI-Navi: a novel indoor navigation system for visually impaired people. In *Proceedings of the 12th International Conference on Computer Systems and Technologies* (pp. 365-371). ACM.

12. Kotanen, A., Hännikäinen, M., Leppäkoski, H., & Hämäläinen, T. D. (2003, April). Experiments on local positioning with Bluetooth. In *Information Technology: Coding and Computing [Computers and Communications], 2003. Proceedings. ITCC 2003. International Conference on* (pp.297-303).IEEE.