Instant Indoor Localization

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Abstract

Lot of advances are made in the field of localization using Global Positioning System (GPS), Wi-fi and Bluetooth. However, while considering indoor localization, a system capable of determining position within indoor settings without use of any infrastructure support is desired. We accomplish such a system by making use of Bluetooth signals combined with acoustics, accelerometer and compass measurements to achieve instant indoor localization.

Introduction

Indoor positioning of a mobile node using Bluetooth has been for quite some time. Though GSM/Wi-Fi can be used for localization in indoor settings, following are some of the drawbacks:

1. To use GSM/Wi-Fi, one has to war-drive the area and create a map of such access points. This war-driving is computationally very expensive and incurs a lot of environmental damage too.

2. Wi-Fi based localization is possible only in urban areas where a dense population of access points is available. Since most part of the world is not Wi-Fi covered, it is necessary to develop a system which will work effectively without any infrastructure support. Cell towers do not produce the required accuracy with positioning.

3. As per the research conducted by Injong Rhee GSM and Wi-Fi pose serious tradeoff between localization accuracy and energy consumption.ƒ Wi-fi signals are less Accurate and Power consuming. Also for using wi-fi AOA (Angle of Arrival) is required which needs special antenna for measurements. The greater the signal strength the probabillity of the error increases.

Signal Range α Error probability

4. Global Positioning System (GPS) is only effective in locating a device outside a building. It requires Line of Sight (LOS) to four satellites for accurate positioning. Also GPS has high energy consumption and infrastructure requirements. So GPS could not be used for indoor localization.

Location management and mobility management are important issues for providing ubiquitous computing environment for mobile users. The available technologies GPS, wifi are effective solution only for outdoor localization. Unfortunately these technologies cannot be used in indoor setting to determine the position. Hence our project aims at designing a system which make effective use of Bluetooth, acoustics, accelerometer and compass functionalities in an android phone to localize an indoor position.

Bluetooth is a highly discussed technique for locating a mobile node. Bluetooth uses RSSI values for measuring Signal Strengths. Received Signal Strength Indicator (RSSI) denotes whether the received (RX) power level is within or above/below the Golden Receiver Power Range (GRPR). A positive or negative RSSI (in dB) means the RX power level is above or below the GRPR, respectively, while a zero implies that it is ideal. The lower and upper thresholds of GRPR are loosely bound, leaving them to be device specific. The RSSI reported by a Bluetooth device is completely dependent on the device's GRPR and its power control mechanism. So the RSSI values of Bluetooth nodes are highly fluctuating due to which clear signal strength is difficult to obtain. But by taking several measurements of Bluetooth signals strengths and then taking an average on these values gives better RSSI values over distance. For the signal strength values obtained from Bluetooth measurements, a map matching algorithm is applied in-order to eliminate infeasible co-ordinates. The matching algorithm is explained later. These results are further refined by using acoustic information to know whether the user is indoor or outdoor.

After obtaining the possible co-ordinates by using the Bluetooth and acoustics input we try to localize the position of the user to a single point. We remove all the co-ordinates that are not feasible for the path travelled by the user. This is done by using the accelerometer and compass inputs from the android device to trace the path of the user and then we match it with the co-ordinate point on the map to check the feasibility.

The paper is organized as follows: *Background* gives the details of various technologies used in the project such as Bluetooth, Matching algorithm, Acoustic, Accelerometer and Compass. *System Implementation* describes the implementation of the system. We have then mentioned the *limitations* of our system and concluded with the *future work*.

Background

Bluetooth

The RSSI values measured from Bluetooth signal is not considered to be an accurate measure for estimating distances. The signal strengths highly fluctuate giving inconsistent values. We took repeated Bluetooth signal strength measurements at various distances. The obtained RSSI values are averaged out. The interesting finding we had is, that, there is a steady decrease in Bluetooth signal strength over distance. This proves that Bluetooth signals can be used to predict the distance by taking repeated measurements and averaging it out. This is shown in Fig 1.

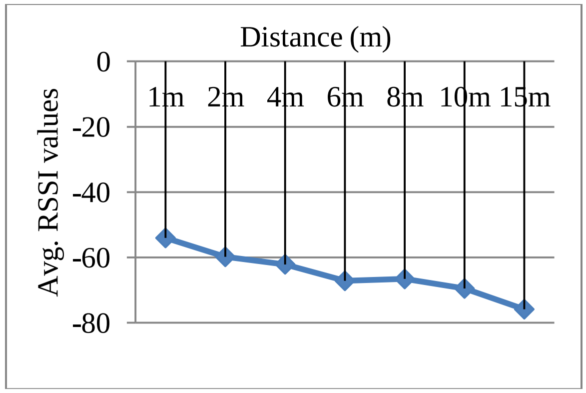


Fig 1. Average RSSI Values vs. Distance

The localization process starts with a preparatory phase. The floor map of the building is first obtained. The map is then split into sections, each section of a specific area. In our model, we split the floor map (70m x 80m) into seventy rows and 80 columns. Then the sections are plotted in x-y plain giving x-y co-ordinates to the various nodes on the floor map. With this the map is split into grids with specific co-ordinates for each grid. In the training phase, various Bluetooth signal strength readings (RSSI values) are taken between all possible nodes. This gives the signal strength between any two possible pair of nodes. The signal strength is obtained by considering environmental factors which are likely to affect the RSSI values. Multiple measurements of the RSSI values are taken and averaging is done in-order to eliminate the fluctuations due to various factors. This is obtained using the Qualnet pathloss simulator. In the final phase, the actual process of locating the mobile node is carried out.

Matching

A matching algorithm is applied in iterations in-order to filter out the impossible co-ordinates of the user in the floor map. The algorithm is defined as follows

m^k : V^k_{node} (set of k nodes) → V^k_{map} (set of k points on map) is called a level-k matching
M^k : a set of level-k matching

Algorithm (probably optimal)
start with M^0=*empty*, k=*0*
repeat until $k = |V_{node}|$
choose a new node (say u) from V_{node}

check all possible level-($k+1$) matching in $M^k \times \{u \to V_{map}\}$ and choose feasible ones as M^{k+1}

$k \leftarrow k + 1$

From the training set, we have a complete set of points available in the flow map. The matching algorithm starts with (k=0) for which all the co-ordinates in the floor map are considered. V_k is the total number of other Bluetooth devices available with which the user measures the signal strength values. Then two pairs of nodes are considered, and for the signal strength values between them, only those set of possible co-ordinates are filtered out from complete path-loss training data. With just two pair of nodes a lot of possible co-ordinates would be obtained. This is because with just a pair of nodes, the two pair os co-ordinates could lie anywhere in the floor map which satisfies the signal strength. Suppose if there are more number of nodes then the co-ordinates that satisfy for the available signal strength values is greatly reduced. This is shown from Fig 2 and Fig 3.

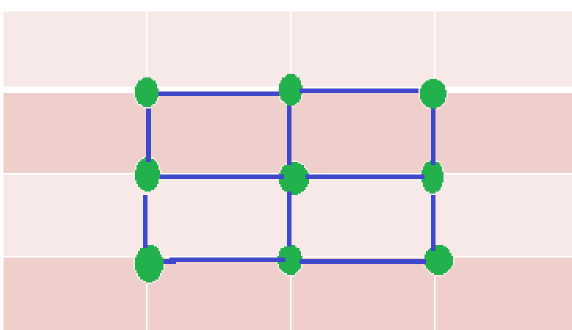


Fig 2. Possible combinations for 2 nodes

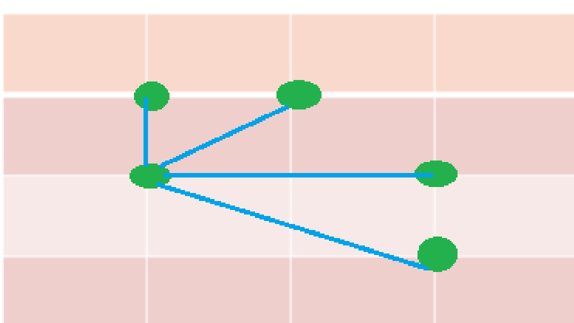


Fig 3. Possible combinations for 5 nodes

Thus the process is repeated by increasing the number of available Bluetooth nodes. It is found that a great number of co-ordinates could be eliminated by increasing the number of Bluetooth nodes. This is shown in Fig 4.

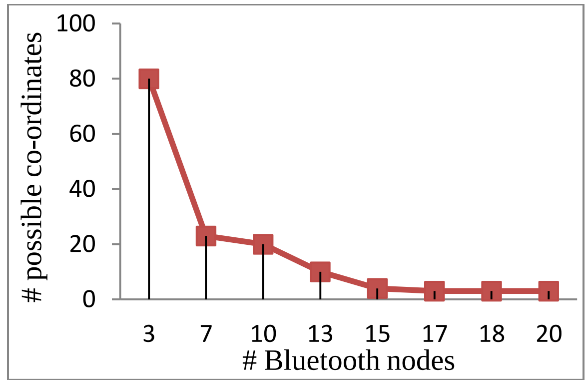


Fig 4. Possible co-ordinates as against number of bluetooth nodes

Accelerometer and Compass

In our project we make use of Android functionalities of accelerometer and compass to facilitate the matching algorithm in determining a fixed co-ordinate location of a person in indoor setting. For this purpose, it is essential to understand the basic working of accelerometer and compass in android programming. The coordinate-system is defined relative to the screen of the phone in its default orientation. The axes are not swapped when the device's screen orientation changes. The X axis is horizontal and points to the right, the Y axis is vertical and points up and the Z axis points towards the outside of the front face of the screen. In this system, coordinates behind the screen have negative Z values.

By using the accelerometer, we are able to determine the step counts of a person and also the distance the person is covering. This information is used in the process of determining a person’s location to a fixed co-ordinate point on the map with every step he takes.

The net acceleration calculated using all the 3 axes:

$$Magnitude = \sqrt{x^2 + y^2 + z^2}$$

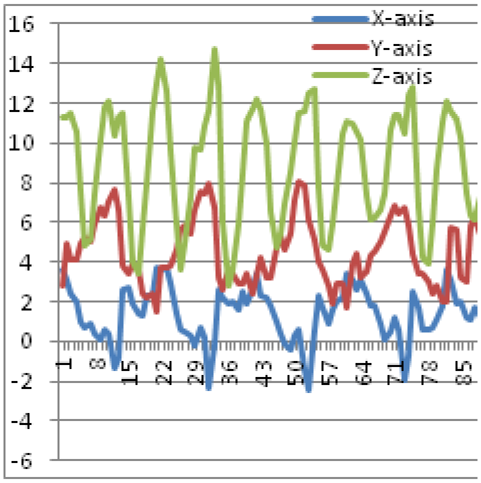


Fig 5. Accelerations along X, Y and Z axes

Using this, the results are not accurate as acceleration along x-axis is very noisy. The reason for this is x co-ordinate is rarely ever changed while walking. When moving in forward direction with the phone flat in one's hand, it is only the y co-ordinate and to some extent z-axis values that change and affect the result. Since our purpose of using this is to determine the step counts and hence the distance, we have used the revised formula for calculating the magnitude of the accelerometer:

$$Magnitude = y^2 + z^2$$

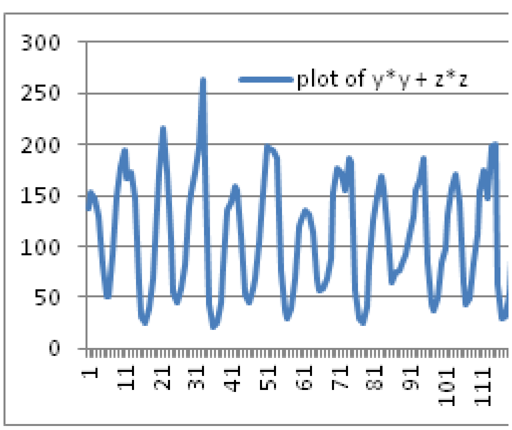


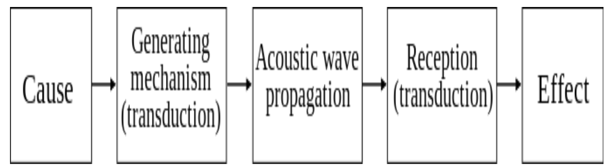
Fig 6. Magnitude as a plot of accelerations along Y and Z axes

This helps us obtain a fixed set of range for considering threshold. This can be used to determine the step as a measure of 2 threshold values.

By using compass, we are able to determine which direction the person is walking in and eliminate all the points which indicate that he is walking into either a wall or an empty open space. This is again used in reducing the number of possible valid location co-ordinates to just one.

Acoustic

The study of acoustics revolves around the generation, propagation and reception of mechanical waves and vibrations.



This concept is used to find the information about the user environment. Like there is a presence of reflections in a closed room and these reflections are absent in open space. Also the android phone can be used to behave like a sonar to find the distance between the phone and the nearest wall by using the round trip time of the sound and its first reflection. This distance can eventually be converted into the room size measurement.

A Beep sound was generated from the android phone using the pre-recorded audio and sound pool. Then in parallel the application will start recording the audio activities. This recorder will thus record the generated audio and the reflections if any as well. Android takes in the audio samples and these samples can then be used to study and find out the reflections.

When the android recorder takes in all the samples, each sample is converted to its RMS value to find the amplitude of sound at each sample. These RMS values when plotted as a graph shows some unique pattern with reflections and without reflections.

The pattern of the RMS values of the samples taken in the closed room was like Fig. 5 and the pattern for the RMS values of the samples were taken in open space was like Fig.6

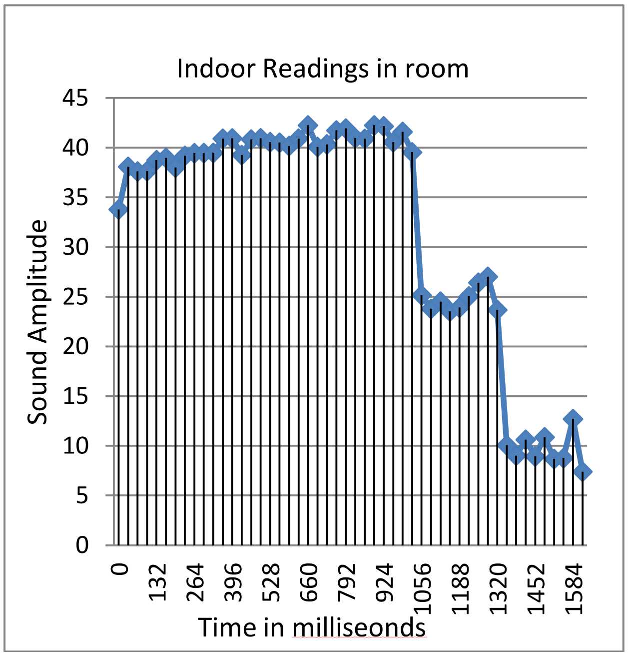


Fig 7. Indoor readings

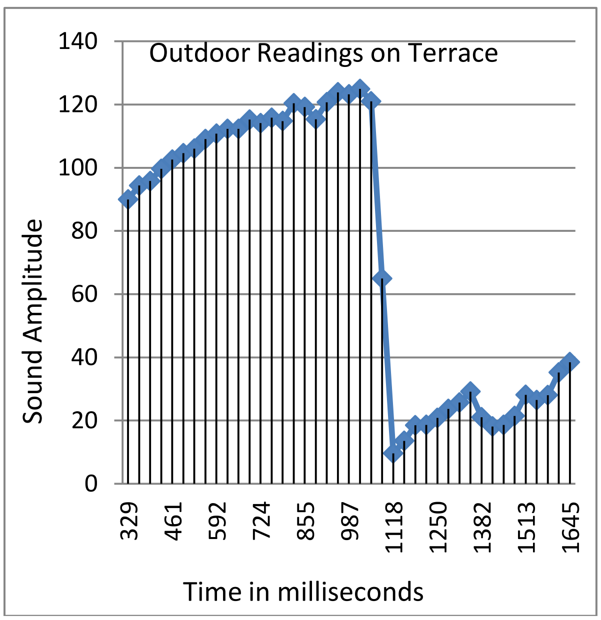


Fig 8. Outdoor Readings

These graphs show that after the end of the pre-recorded voice played by the android phone itself, there is a pattern in the indoor readings which signifies the multipath reflections that the phone receives even after the original signal dies. This pattern is absent in the second graph because of the absence of the multipath reflections. This pattern remains fairly constant for many indoor and outdoor readings.

There was another experiment to find out the size of the room. The android phone generates 17KHz frequency sound and then the recorded sound is filtered using the Goertzel Algorithm to find the level of the particular frequency present in the samples. The Goertzel algorithm is Digital Signal Processing (DSP) technique for identifying frequency components of a signal. The following graph shows the magnitudes returned by the Geortzel algorithm when the sound was played in the closed room.

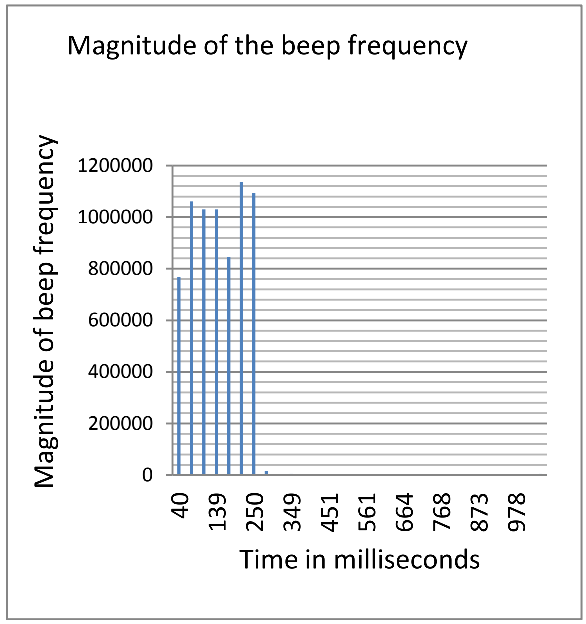


Fig 9. Goertzel Output for Indoor

Here since the first sample gives the magnitude of the frequency and takes 40 milliseconds to take the next sample, we lose many samples in the process. This limitation of android makes it difficult to find out the room size of rooms smaller than 13.6 meters, since any room smaller than that will have its reflection in the same sample it has its self sound. Working around this limitation and finding the exact room size will be the future work.

System Implementation

Three part implementation:
Part I: Map Construction and Implementation of Matching Algorithm

Part II: Eliminating infeasible points using acoustic information
Part III:
Calculating step counts
Integrating accelerometer and compass functionalities
Reducing the set of valid candidate points down to one location co-ordinate
Representing the results as aesthetic GUI

Part I:
The first part of our project was construction of the location map. For the purpose of our project we used the floor map of third floor Boelter Hall at UCLA. From the map we first obtain the size of the site and plot co-ordinates at regular distance, in our case as the Bolter hall size was 172*70 we plotted the co-ordinates for every 2 meter distance. Thus we obtained the following map of Bolter Hall with 86*38 co-ordinate points.

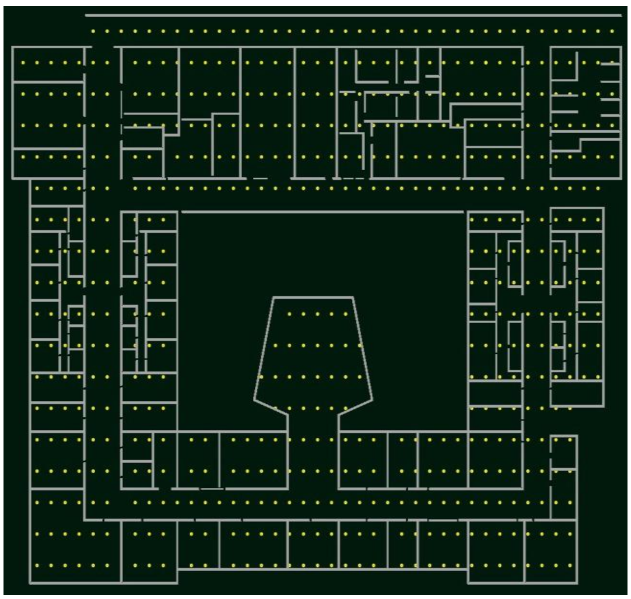


Fig 10. Co-ordinates on Boelter Hall

Once we have the co-ordinates on the map we then reduce the map to a string matrix of the size 38*86. In order to implement a string matrix we used the following symbols to denote co-ordinate points that fall on particular positions like, w: wall, 1: valid location co-ordinate, 0: open space, C: closed corridor, OC: open corridor.

w	w	w	w	w	w	w	w	w	w	w	w	w	w
C	C	C	C	C	C	C	C	C	C	C	C	C	C
w	w	w	w	w	w	w	w	w	w	w	w	w	w
C	w	1	1	1	1	1	1	1	w	1	1	1	1
C	w	1	1	1	1	1	1	1	w	1	1	1	1
C	w	1	1	1	1	1	1	1	w	1	1	1	1
C	w	w	w	w	w	w	w	w	w	w	w	w	w
C	w	w	w	w	w	w	w	1	w	1	1	1	1
C	w	w	w	w	w	w	w	1	1	1	1	1	1
C	w	1	1	1	1	1	w	1	1	1	1	1	1
C	w	1	w	w	w	w	w	1	w	w	w	w	w
C	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC
C	w	w	w	w	w	w	w	w	w	w	w	w	w

Fig 11. Matrix of Boelter Hall

Once the map is ready with all the points set, next step was to compute path loss matrix. Our system starts with scanning all the Bluetooth devices in the vicinity to obtain the RSSI values of the link between the user and the surrounding devices. Then we match the RSSI values obtain for each pair with the results of Path loss Simulator. Path loss values of Bolter Hall are pre determined using Qualnet simulator. The output of the pathloss simulator is a set of possible co-ordinate (x, y values) for a given RSSI value. RSSI value of each pair is used in a k-level matching algorithm to remove all infeasible co-ordinates. In this process we get the intersection of the co-ordinate point which gives us the possible location of the current user.
Thus the signal strength between Bluetooth devices can be effectively used to find the possible set of co-ordinate locations which are then given as input to Part II and III.

Part II:
To make use of the acoustic patterns to differentiate between the indoor and outdoor the following algorithm was implemented on the android phone.

Algorithm:
-DIP = Set of points whose consecutive values cross a predefined threshold
-Recursively consider the local minima and find the first DIP which is the end of the beep
-If
-some higher values – (Multipath Reflection)
-Another DIP – (End of Multipath reflections)
then INDOOR

-If
-huge set of higher values – (noise)
-absence of second DIP
then OUTDOOR

This algorithm was implemented on the readings obtained from the Boelter Hall corridor. The readings were taken at the open and closed corridor of the Boelter hall. The readings for both these scenarios are shown as follows:

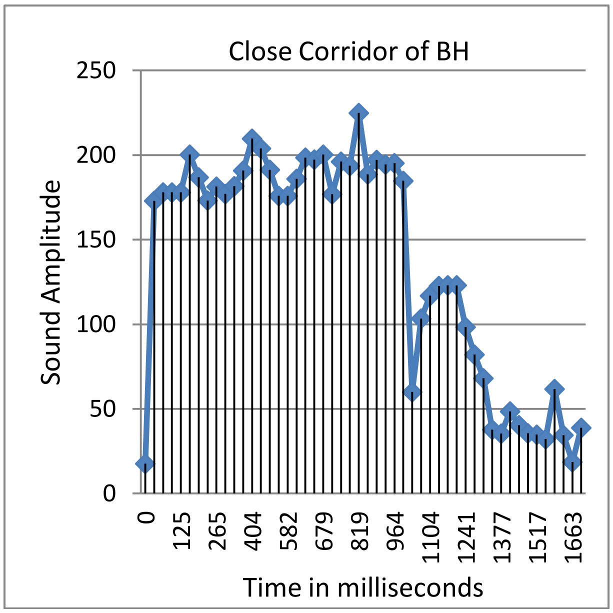


Fig 12. Close Corridor of Boelter Hall

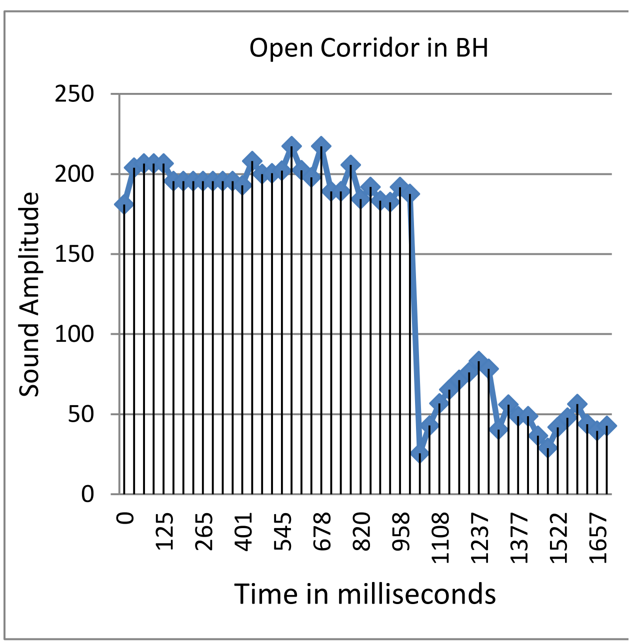
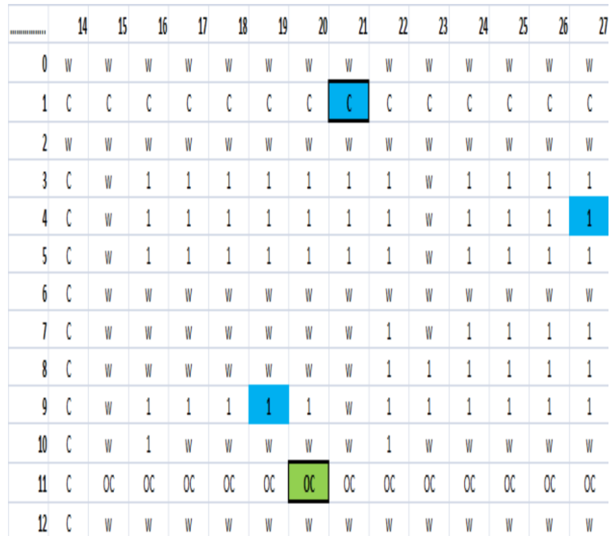


Fig 13. Open Corridor of Boelter Hall

Thus the algorithm can find out if a person is standing in the open or close corridor. This is used in the main project to remove the infeasible points from the set of points returned from the matching algorithm.

Consider the following co-ordinates to be the possible user locations.



########	14	15	16	17	18	19	20	21	22	23	24	25	26	27
0	W	W	W	W	W	W	W	W	W	W	W	W	W	W
1	C	C	C	C	C	C	C	C	C	C	C	C	C	C
2	W	W	W	W	W	W	W	W	W	W	W	W	W	W
3	C	W	1	1	1	1	1	1	1	W	1	1	1	1
4	C	W	1	1	1	1	1	1	1	W	1	1	1	1
5	C	W	1	1	1	1	1	1	1	W	1	1	1	1
6	C	W	W	W	W	W	W	W	W	W	W	W	W	W
7	C	W	W	W	W	W	W	W	1	W	1	1	1	1
8	C	W	W	W	W	W	W	W	1	1	1	1	1	1
9	C	W	1	1	1	1	1	W	1	1	1	1	1	1
10	C	W	1	W	W	W	W	W	1	W	W	W	W	W
11	C	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC
12	C	W	W	W	W	W	W	W	W	W	W	W	W	W

Fig 14. Matrix map after using acoustic information

A person moving in West can be positioned in any of the shown locations. If the acoustic data suggests that person is standing in indoor environment, then easily the OC co-ordinate is eliminated. On applying this information on whole co-ordinate set, we can reduce the consideration points to a good extent.

Part III:

After removing the co-ordinates that are not feasible based on acoustic information we narrow down the set further to as few points by using accelerometer and compass that tracks the user path.

For every step taken by the user the output of the accelerometer varies along y-axis and z-axis. Analyzing the graph of accelerometer variation we see that the magnitude increase and decrease once for every step. Now we set two thresholds on this variation to determine the number of steps taken by the user. Using the step count we can calculate the distance travelled by multiplying the step count with 0.7m (average step size of men is 0.75m and women is 0.65m). The direction of motion of the user is determined by the compass output and we store this direction information in a hash table for every two meters using the corresponding step count. Thus each entry in the hash table gives the information of direction and the distance travelled by the user at each co-ordinate of our map.

As the user walks around the place for every two meter travelled we obtain the direction and eliminate from the set of possible co-ordinates obtained earlier those points that are not feasible like those running into a wall, outer space etc. We repeat this step for every two meter travelled by user in any direction and in the process narrow down the possible co-ordinate point to until we find a single co-ordinate point which gives us the location of the user.

Working of Android Application:

We have implemented our project as an application in the android phone and every user whose position is required to be determined will be running this application on his phone.

1. Once the user enters a building he downloads the floor map o f the location and analyzing that we create a map with the co-ordinate points.
2. Next, the user scans through the Bluetooth devices by pressing “Scan Bluetooth” button in the application.
3. We have built in a feature in the application that displays the map along with the user possible locations obtained from the Bluetooth scan. These possible locations keep reducing on the map for every two steps covered by the user in different direction until we find a single point on the map.
4. With the help of “Show Map” button, we are able to show to the user his near to exact location on the map.

Experimental Results

Evaluation

The Acoustic signals obtained by the application are used to find out and eliminate the impossible points. The accuracy of the results depend on many factors. And so the multiple readings were taken in the Boelter hall corridors to find out the accuracy of the acoustic measurements. These readings were taken by keeping the phone in two positions. One is parallel to the parallel walls of the corridor and other is perpendicular to the parallel walls of the corridor. Around 20 readings of the indoor corridors and 16 readings of the outdoor corridors were then taken each in these two positions. The accuracy for how many times did the indoor corridor gave the correct result as ‘indoor’ and how many times did the outdoor corridor gave the correct result as ‘outdoor’ is given in the following graph.

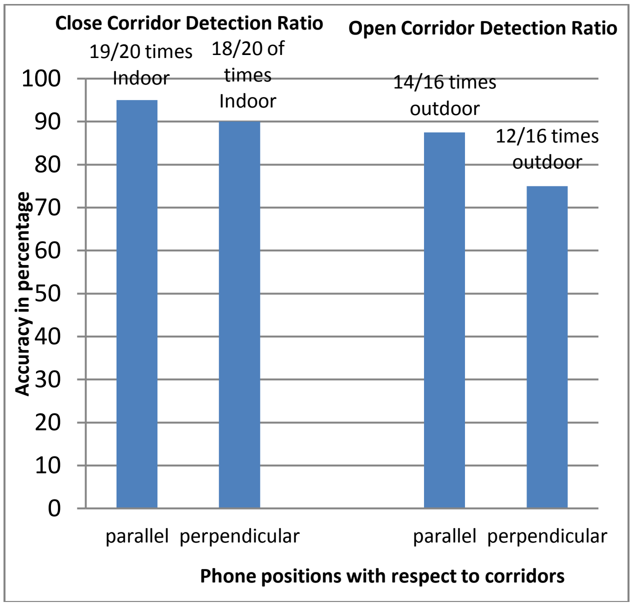


Fig 15. Accuracy for Open and Close Corridor

We have evaluated the system by running it ten times for the same position of the user to see the accuracy of the system in determining users location. Analyzing the outputs, we have considered 3 cases for same:

Case 1: Location co-ordinate within 3meter distance from the actual position

Case 2: Location co-ordinate in a distance range of 3meters to 6 meters from the actual positon.

Case 3: Location co-ordinate at a distance more than 6meters from actual position

Out of the 10 iteration, 30% of the results fell in case 1, 60% in case 2 and 10% in case 3. The distance error can be plotted as shown below:

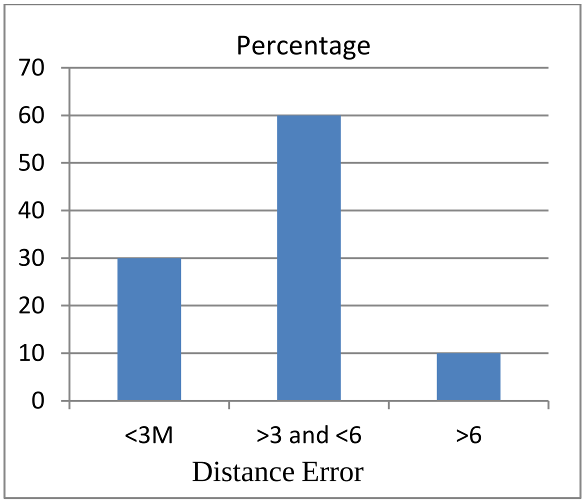


Fig 16. Accuracy for localization

The reason for such variations can be attributed to the fact that RSSI values of measured signal strengths vary with time. Also, the result of our system depends on the number of Bluetooth devices it scans and connects in every iteration. In some iteration, it connected to as many as 10 and in some others it connected to as less as 4. Also, the strength of Bluetooth signal varies from device to device. Hence the accuracy also varies.

Limitations

1. To start with, the application requires a few set of Bluetooth devices to start localization. With only 1 or 2 devices in the vicinity, the system fails to return any relevant results.
2. RSSI values are highly unstable. They vary for the same set of co-ordinates over a period of time. This makes their usage highly unreliable. Hence we are required to conduct a set of iterations to localize a user position.
3. Computation time for matching algorithm is high. On obtaining the RSSI values, they have to be compared against a huge set of pre-determined Qualnet simulator results and this comparison takes a lot of time and increases the time required to return result.
4. Accelerometer outputs are very sensitive to unsteady motion. Variation is observed when phone is moved in or out of the pocket. Also, swing motion affects the acceleration.

Future Work

The time consumption of the matching algorithm increases as there are more number of Bluetooth devices. This could be optimized further through a better matching algorithm. Currently the RSSI signal fluctuations are avoided to the maximum extend by taking repeated measurements and averaging it out. A more detailed analysis has to be done, trying to combine RSSI value with Link Quality (LQ) and Transmit Power Level (TPL) measurements in order to obtain precise location of the Bluetooth node. We can decrease the computational time by using acoustic signals to determine the room size.

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