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CROWDSOURCING BASED MICRO NAVIGATION SYSTEM FOR VISUALLY IMPAIRED

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**CROWDSOURCING BASED MICRO NAVIGATION SYSTEM FOR VISUALLY
IMPAIRED**

A Thesis Presented

by

QUAN SHI

Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL AND COMPUTER ENGINEERING

September 2018

Electrical and Computer Engineering

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CROWDSOURCING BASED MICRO NAVIGATION SYSTEM FOR VISUALLY IMPAIRED

A Thesis Presented

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ABSTRACT

CROWDSOURCING BASED MICRO NAVIGATION SYSTEM FOR VISUALLY IMPAIRED

SEPTEMBER 2018

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Directed by: Professor Aura Ganz

Mobility and safety are primary concerns for blind and visually impaired (BVI) users when navigating in unfamiliar environments. Typically, a sighted person can locate a place of interest if they are provided guidance while approaching within a few meters of the location. However, this resolution of guidance is often insufficient for blind travelers. In this thesis, we propose a crowdsourcing based micro navigation system for BVI users in both indoor and outdoor environments. To achieve this goal, our system includes three parts: crowdsourcing reports generated by volunteers using the **volunteer application**, landmarks validation performed by the system administrator using the **admin application**, and the BVI user navigation obtained through the **BVI user application**. In addition, we provide accessible audio navigation for indoor and outdoor environments required to deliver real time step by step landmark information to BVI users.

Crowdsourcing is enabled by the contribution of many volunteers which use the proposed **volunteer application** to report specific landmarks in the environment including their location, description and surrounding landmarks. These reports which are uploaded to the server database, are validated by the **admin application** which updates the server database and deploy BLE tags for indoor environment. **The BVI user**

application localizes users by GPS outdoors and BLE proximity technology indoors.

Using the real-time location of users and the **landmark node graph** we built from updated server database, this application provides the **shortest route** to the destination and real time “micro-navigation” information describing how to get to the next landmark’s location with corresponding distance & orientation. This information is used to make users well aware of where they are, and guide users to their chosen destination within a cane’s distance.

This application will improve the confidence and safety of BVI users by enabling them to explore and get navigation in both indoor and outdoor environments.

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CHAPTER 1

INTRODUCTION

The World Health Organization (WHO) reported in October 2017 that 253 million people are estimated to be visually impaired worldwide; 36 million are blind and 217 million have low vision. Blind and visually impaired (BVI) people with a very limited (even not at all) sense of sight have significant challenges for navigating independently in an unfamiliar environment. They might encounter a lot of difficulties in mobility and even fall in dangerous situations. The main challenges that make it difficult for the visually impaired people to navigate by themselves include: determining their locations and orientation, obstacle avoidance, finding the important objects, and knowing the distances between themselves and the objects [1]. The system introduced in this paper focuses on landmark based navigation aid application for visually impaired people.

This system provides an idea to collect the information from “thousands of discoveries,” from the contribution of many blind and sighted volunteers, into an application to provide the “micro-navigation” information necessary to lead BVI user move conveniently and confidently. The “discovery” is recorded using the report application and all the “discovery” places information will be checked and verified by offline engineers who use admin application to update new landmarks on the map. The “recollection” is at the traveler’s fingertips, sensitive and responsive to their current location. BVI can use the users’ app to simply localize themselves and get navigation instructions to the destination chosen both indoors and outdoors.

This thesis document is organized as follows: In Chapter 2 we provide necessary literary survey for this thesis work, and then we introduce overview of this system in

Chapter 3. Chapter 4 and 5 describes the volunteer application and admin application, Chapter 6 introduces BVI user application, Chapter 7 provides demo outdoors and indoors for our system and Chapter 8 summarizes this thesis and proposes the future work.

CHAPTER 2

LITURATURE REVIEW

Mobility, the most involved activity in everyone's life, relies mostly on the vision. Mobility in an unfamiliar environment is not always an easy task even for sighted people. Therefore, mobility aid has an important role in assistive technologies for BVI people. Nowadays, numbers of BVI navigation-assistance tools for indoor and outdoor environments have been proposed [2 - 4]. In general, localization can be considered as a principal basis for these tools. In outdoor navigation, even GPS has become widely used, many issues still need be addressed when applying these solutions for visually impaired people, such as missing places (working zone, etc.). Furthermore, since GPS is not always available for an indoor environment, different techniques have been proposed for indoor navigation such as Wi-Fi, camera, BLE (Bluetooth Low Energy), etc. [5 - 7]. Considered that each technique has its own advantages and disadvantages, this work aims to improve the BVI navigation by crowdsourced description combining BLE and GPS based localization technologies.

In this chapter, we will give a literature review focusing on the existing landmark based navigation projects and compare them with our system design.

The landmark knowledge represents the most frequently-used category of navigation cues used by pedestrians [9] (unlike distance, junctions or road type). Ross et al. [10] have shown that inclusion of landmarks within pedestrian route itinerary increased confidence of users and reduced navigation errors. Contributions from Ross [10] also extend to voice-only navigation [11], where inclusion of landmarks was clearly more preferred by participants.

Numbers of groups have explored the use of crowdsourcing for assisting blind users in various applications. BlindSquare [15] is MIPsoft's GPS navigation software for iPhone and iPad. It differs from other navigation applications by using crowd sourced data; it uses Foursquare for points of interest and OpenStreetMap for street information to provide your current address, as well as information about the location of the nearest street intersection and venues around you. BlindSquare can periodically announce the distance and direction while you are traveling. The result of this project clearly proves that crowdsourcing data can provide abundant information about places for BVI users, which can increase their confidence. However, this system cannot provide landmark based context information and navigational clues, since it just describes the environment, and announces points of interest as well as street intersections as you travel.

BlindWays [16] provides a means to collect the information from the contribution of hundreds of blind and sighted volunteers to provide the “micro-navigation” information to lead the traveler closer to the bus stop. It picks up where GPS leaves off – guiding travelers to the bus stop sign within a cane’s distance using reliable navigational clues provided by members of the community. The adding clues provide BVI users convenience and confidence, and ensure that when the bus arrives, the traveler is standing in the right spot without the need to ask for assistance, and no longer “missing the bus”. The crowdsourced clues bring users to within four or five feet (the average length of a white cane) of their bus stop so they can touch the signpost and verify they are in the right spot. It shows that the context information gives visually impaired commuters confidence for traveling independently.

Compared with the above existing navigation system, this document introduces a landmark based BVI navigation system using crowdsourced description for both indoors and outdoors environment combining BLE and GPS based localization technologies. Moreover, this system can provide detailed context information based on users' location changing. We compare this system, BlindSquare and BlindWays in Table 1 as follows.

	BlindSquare	BlindWays	Our System
Custom Places	No	Customize landmark near bus stop with description	Customize all types of places with GPS location and navigation tips
Places validation	No	Description validation	Yes
Distance & Orientation	Yes	No	Yes
Navigation clues	Surrounding places	Bus stop description and nearby landmark object	Places description including type, direction, nearby landmarks etc.
User moving guidance	No	No	Users can know that if they are moving towards the landmark or away from it
Indoor localization	Yes	No	Yes

Table 1: Comparison between BlindSquare and BlindWays

In paper [17], Chen-fu and Max introduce WorkZone Alert, which is a work zones notification system using BLE Technology to trigger in-vehicle messages. The BLE tags will trigger spoken and contextual messages in existing smartphones located in vehicles passed by the tag. This project developed a smartphone app to detect BLE tags in the environment and automatically announce audible message through the text-to-speech (TTS) interface on the phone, and another admin app for the work zone deployment contractors, which allows the staff in the field to submit a request for

message updates at the location where a BLE tag is installed. This app automatically determines current latitude/longitude location of the smartphone beacon, scans for Bluetooth beacons in the vicinity, and then lists identified Bluetooth tags. The comparison between our system and work zones notification system is detailed in Table 2.

	WorkZone Alert	Our system
Motivation	Design and test a work zone alert system that announces additional messages through the users' smartphones.	Design a landmark based navigation system for visually impaired people
Technology that triggers messages when approaching	Bluetooth Low Energy	Outdoor: GPS & Compass Indoor: Bluetooth Low Energy
Design & Implementation	The system includes a spatial database, a middleware for data transactions, two smartphone app, and BLE tags	The system includes two landmark databases, a web service, volunteer app, admin app and BVI user app, and BLE tags
Reconfigurable	Need to deploy BLE outdoors and avoid obstacles and the wet situation	No hardware outdoors
	Specific Environment	A generic system that can work with any situation

Table 2: Comparison between WorkZone Alert and Our system

PERCEPT-II [12] is a low cost and user friendly indoor navigation system for blind and visually impaired users. Using an Android smartphone that runs PERCEPT-II application with accessibility features, the blind user obtains navigation instructions to the chosen destination when touching specific landmarks tagged with Near Field Communication tags. The system was deployed and tested in a large building at the University of Massachusetts at Amherst. The comparison for indoor environment between our system and PERCEPT-II is detailed in Table 3.

	PERCEPT-II	Our system
Goal	Indoor navigation	Indoor and outdoor navigation
Technology	NFC tags; Andriod	iBeacons; IOS
Principle	Node - Link structure	Trilateration localization, RSSI Proximity and Node - Link structure
Design & Implementation	The system provides route between every two landmarks by generating the Node-Link structure that includes nodes (represent landmarks) and links (represent the physical connections between the nodes).	The system provides route from user to destination selected by generating graph structure, and corresponding navigation instructions. The landmark information is collected by crowd and verified by engineers.
Reconfigurable	Engineers need to know all the landmarks' information.	Landmarks' information can be reported by the crowd.

Table 3: Comparison between PERCEPT-II and Our system

Be My Eyes [13] is a mobile app designed to bring sight to the blind and visually impaired. With the press of a button, the app establishes a live video connection between blind and visually impaired users and sighted volunteers. Every day, volunteers are lending their eyes to solve challenges both big and small in the lives of the blind and visually impaired. The comparison between our system and Be My Eyes is detailed in Table 4.

	Be My Eyes	Our system
Goal	Help BVI users solve daily life challenges by volunteers anywhere	Help BVI users localize and navigate themselves by volunteers nearby
Technology	Live video call	Virtual iBeacons

Design	BVI users can get visual assistance by tapping the button on the screen. Be My Eyes will call a sighted volunteer and establish a video connection between them using the phone's camera of BVI users	If BVI users get lost or need navigation assistance, they can tap button to make their phone a virtual BLE for nearby volunteers to search. Volunteers can get phone numbers of nearby BVI users if they're in need.
Cost	Cloud database and the connection for live video are expensive. Wi-Fi or cellular is needed.	No Wi-Fi or cellular needed. No database needed. Light and cheap.

Table 4: Comparison between Be My Eyes and Our system

CHAPTER 3

OVERVIEW OF SYSTEM

3.1 Motivation

People with vision impairment have different perception and spatial cognition compared with sighted people. Blind pedestrians primarily rely on auditory, olfactory, or tactile feedback to determine spatial location and find their way. They are more vulnerable to collision due to insufficient information, such as distance and heading, and time for planning a detour around obstacle.

Here are barriers for visually impaired people during their movement: 1. inaccuracy of GPS; 2. missing or inaccurate place information on the map, such as a complicated buildings entrance, a work zone, a roundabout, etc.; 3. lack of real time information about surrounding landmarks, such as the distance and orientation, relative position of users to landmark, as well as context information about landmarks like nearby buildings.

Therefore, our goal is to design an accessibility mobile application which provides:

1. A volunteer report application for sighted users to submit clues or missing / inaccurate landmarks on the map.
2. A landmarks data updating system for admin to update landmarks information, including nearby landmarks, navigation clues and position description. For indoors, admin can set up iBeacons around the landmarks and save corresponding information.
3. A localization & navigation application for BVI user to localize and navigate indoors and outdoors with detailed context information for the micro navigation.

4. An assistance system that connects BVI with sighted helpers nearby via virtual iBeacons.

3.2 Proposed Framework

In this section of this chapter, we will introduce the proposed landmark based navigation aid system for visually impaired people.

Figure 1 shows the structure of this system. Our system includes three parts: crowdsourcing reports, landmarks validation and updating, and BVI user navigation. Sighted users can use the report application to submit missing places on the map, such as a working zone, a roundabout etc. Engineers can use the admin application to review reports, verify location information, and simply select the position on the map and set it as a new landmark with context information. For indoors, engineers need to install Bluetooth tags at landmark position. BVI users can localize and navigate themselves and ask for assistance using the BVI user application.

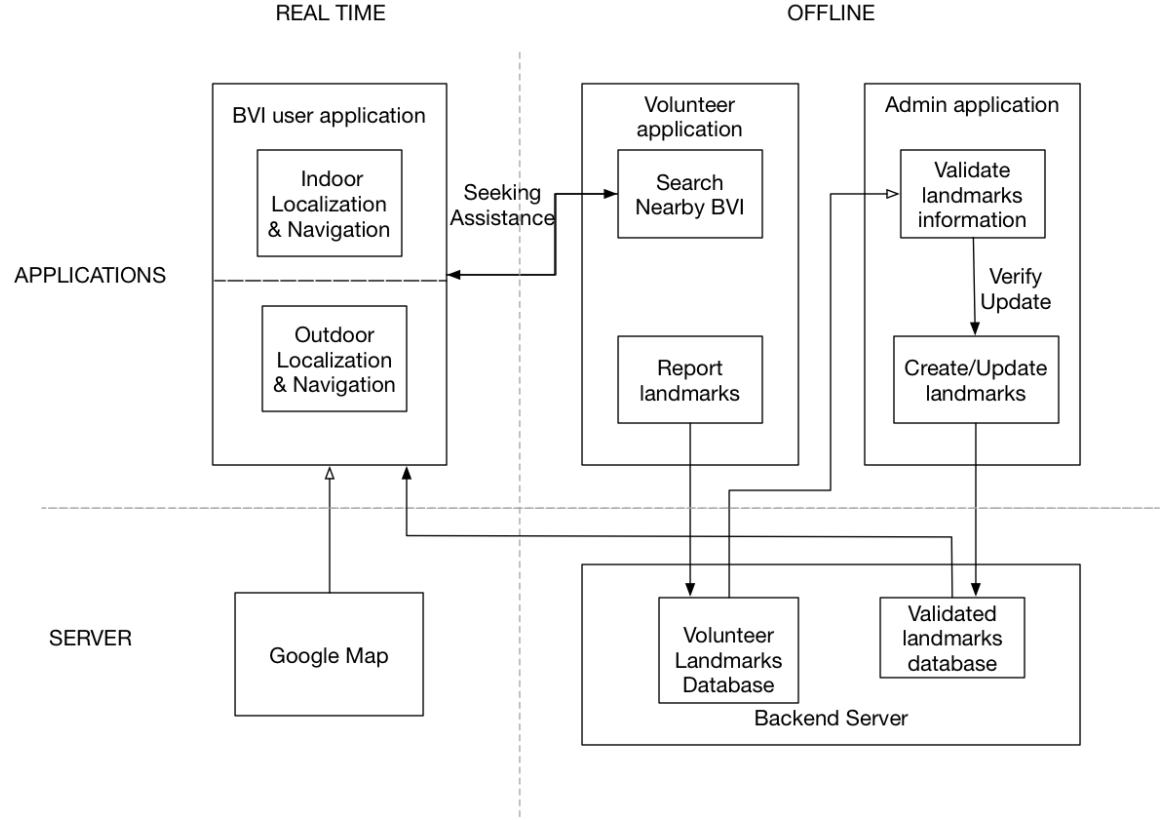


Figure 1: System architecture

3.3 Implementation

- Google Maps

In order to get actual location of the landmark without GPS errors, we use Google Map as a visual tool to select location by just tapping on the map. Volunteer can select exact position on the map to report missing places or clues to the landmarks. Meanwhile, admin can select the position where they install BLE indoors or select area for landmark zones.

- Azure App Service

Azure provides simple backend database for cloud apps, which is easily integrated into our framework. Volunteers can save all the report information for admin to verify.

Admin can review all the reports from database ordered by submission time and update landmarks and BLE information in the database.

- Xamarin

Xamarin is a cross-platform software for application development. With a C#-shared codebase, developers can use Xamarin tools to write native Android, iOS, and Windows apps with native user interfaces and share code across multiple platforms [11].

We use Xamarin - Forms for our IOS application development since it easily transfers to Android or Windows systems.

CHAPTER 4

VOLUNTEER APPLICATION

4.1 Overview

In this section of this chapter, we will introduce the volunteer application. As we can see from Fig 2, sighted users submit the landmark information as well as navigation clues to the backend database.

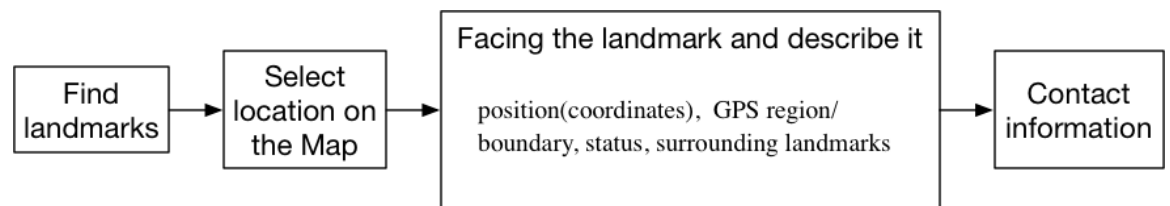


Figure 2: Volunteer System flow

The volunteer application has a local SQLite database which has the basic data for reports and verified landmarks. Volunteers are able to add report data to the local database and then are able to sync this data to an Azure database. They are also able to download verified landmark information by synchronizing local database with Azure database.

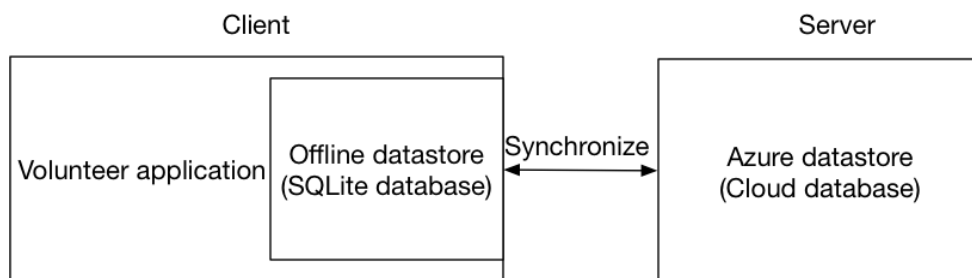


Figure 3: Volunteer System Architecture

4.2 Server Database Schema Design

Our system provides “30 feet of frustration” with clues contributed by volunteers that describe permanent landmarks near users such as a tree, a fire hydrant, and a mailbox. Landmark types are defined here: 1. Work zone; 2. Traffic signal; 3. Roundabout; 4. Crosswalk; 5. Bus station; 6. Buildings entrance.

The crowdsourced clues bring users to within four or five feet (the average length of a white cane) of their destination so that they can touch the signpost and verify they are in the right spot. Engineers are able to call volunteers if there is anything that needs to be checked. Therefore, we have the reports schema as Table 5.

Name	Type	Content	Description
Landmark Location	(double, double)	Longitude and Latitude of the landmark	The actual location of the landmark
Landmark Type	string	Type of the landmark	Such as bus stop, roundabout etc.
Landmark Description	string	Surroundings & navigation clues	Detailed information of this missing place
Date	timestamp	Report submission time	Convenient for engineers reviewing reports ordered by timestamp
Name & phone	string	Volunteer’s contact information	Convenient for engineers to contact volunteers

Table 5: Volunteer reports schema

4.3 Volunteer Application UI

For the user interface of the user report application, we use Google Map SDK to provide a visual map for volunteers to select the landmark location. The latitude and

longitude field will be updated. Since the database cannot have null value, we need to check the required input, and if the required field is empty, an error pop-up will display.

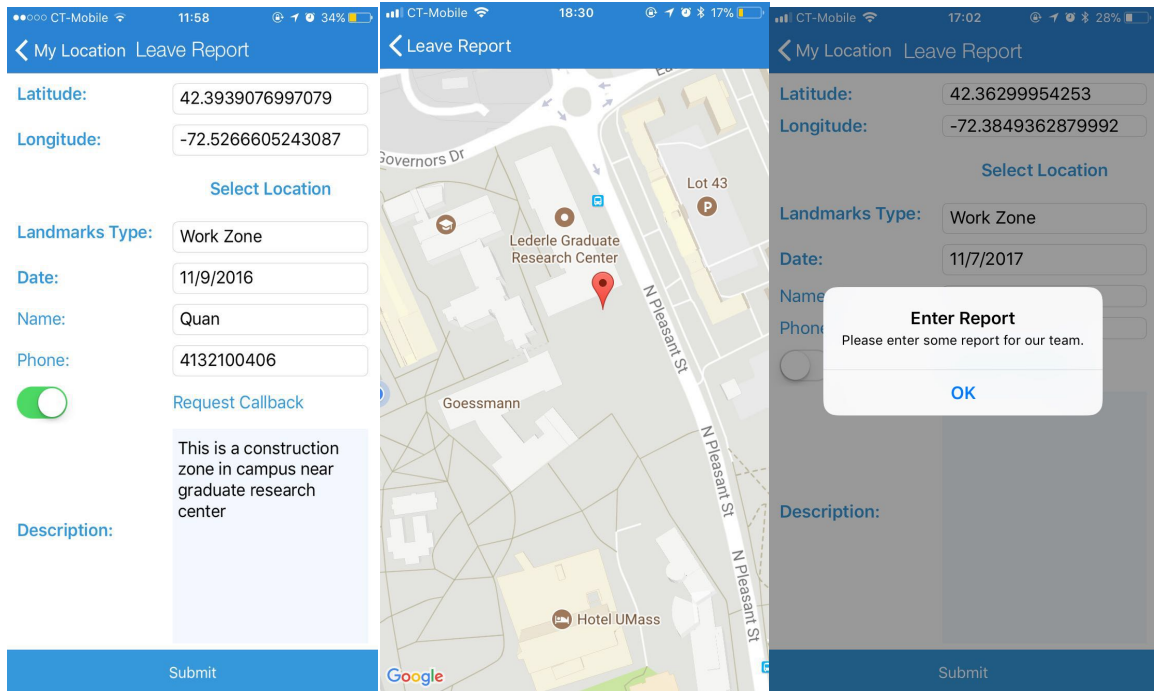


Figure 4: Volunteer User report UI

CHAPTER 5

ADMIN APPLICATION

5.1 Overview

In this section of this chapter, we will introduce the admin application. As we can see from Fig 4, engineers can retrieve all the reported landmarks' information, verify them onsite, and update the landmarks' information with navigation clues to the database for BVI users.

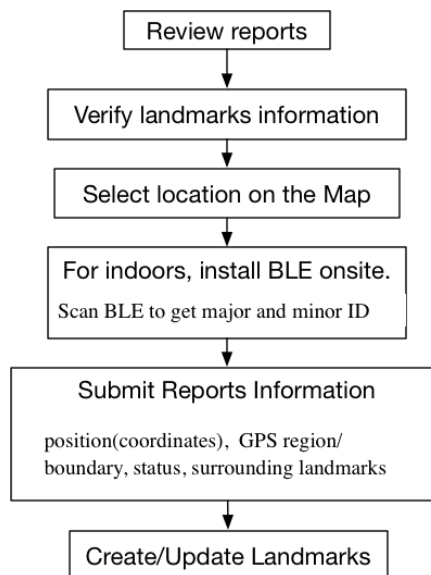


Figure 5: Admin System flow

The admin application has a local SQLite database which has the basic data for reports and verified landmarks. Engineers are able to add/delete/modify verified landmark data to the local database and then are able to sync this data to an Azure database. They are also able to download reports information by synchronizing local database with Azure database.

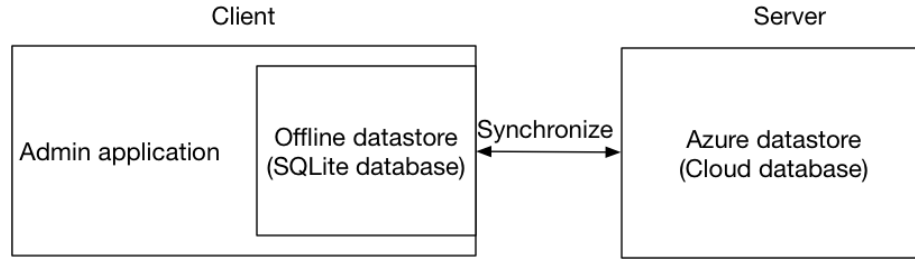


Figure 6: Admin Architecture

5.2 Server Database Schema Design

5.2.1 Graph Nodes Design

In order to navigate users from landmark to landmark, we need to create a landmark graph, which is a Node-Link structure that includes nodes representing landmarks and links, which represent the physical connections between the nodes.

Since each landmark is a node in the graph, we need to link adjacent nodes together. We use key-value pairs to store the adjacent landmarks name and corresponding navigation instructions.

For engineers updating the database, if landmarks are indoors, we need to record the BLE tags information. Therefore, we have the landmarks schema as shown in Table 6.

Name	Type	Content	Description
Landmark Name	string	Landmark name	Indoors or outdoors
Landmark Location	(double, double)	Longitude and latitude of the landmark	The actual location of the landmark
Landmark Type	string	Type of the landmark	Such as a bus stop, a roundabout, etc.
BLE information	string	Including UUID, major-ID, minor-ID.	Only for indoors environment
Landmark Description	string	Address & Description	Detailed information of this missing place such as street direction,

			bus hours, schedules, etc.
Adjacent Nodes	Dictionary<string, string>	Adjacent landmarks name and corresponding navigation instructions.	Key value pairs represent linked landmark name - navigation instructions.
Image	url	Landmark Image URL	Images can be downloaded so that engineers and volunteers can find the landmark easily.

Table 6: Landmark schema

5.3 Review and Validation UI

Engineers are able to use the admin app to review all the reports and corresponding locations on the Google Map. Thus, engineers can go onsite to landmarks from the map to verify location information easily. The admin app also provides a call function, if there are confused reports, engineers can ask volunteers directly.

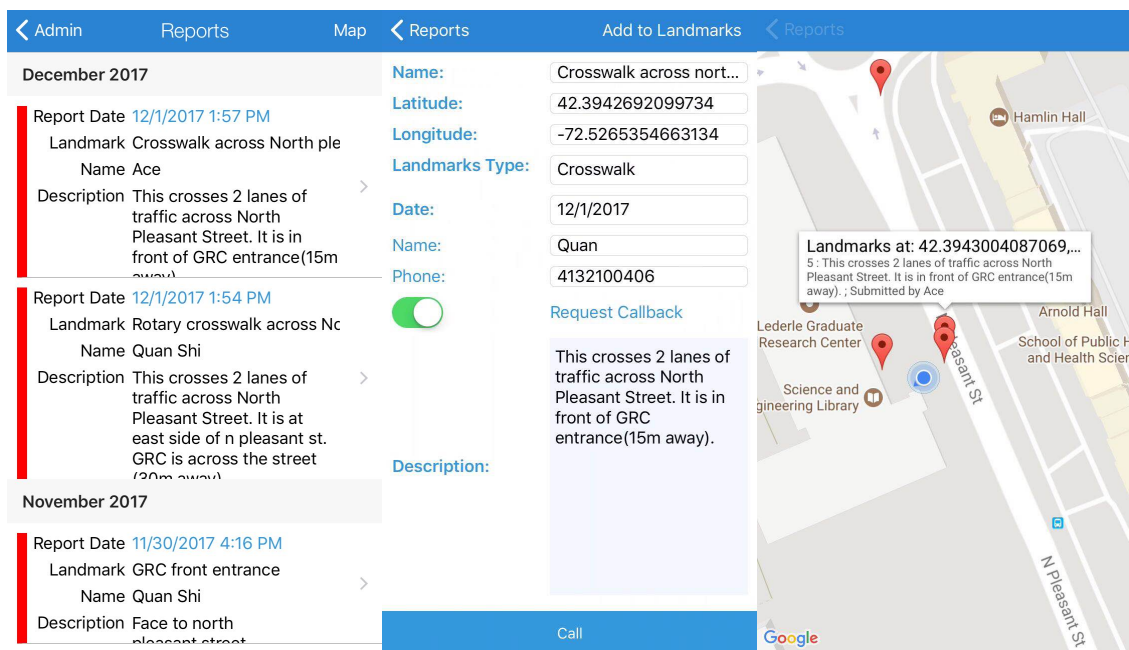


Figure 7: Admin review & validation UI

5.4 Landmark Submission UI

After verifying the landmarks position information onsite, engineers can update the landmarks database by clicking Add to landmarks button in the report page or creating a new landmark. And there are nearby landmark fields, admin can easily link the current landmark with others by entering the adjacent landmark name and the navigation instructions to that landmark. For indoors environment, engineers can install iBeacons and scan it closely to get corresponding BLE information.

Saved landmarks are ordered by the landmark type, which is convenient for searching.

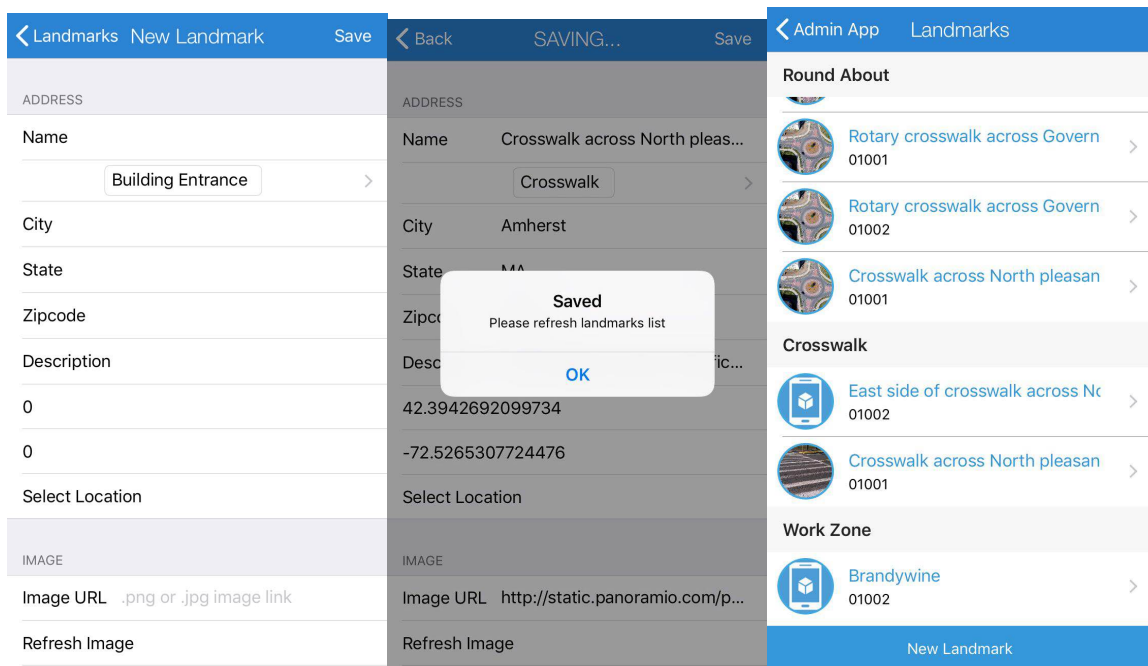


Figure 8: Admin landmark submission UI

CHAPTER 6

BVI USER APPLICATION

6.1 Flow Chart

Our system provides BVI users necessary navigation instructions to the destination in Navigation Mode, and also provides surrounding landmark information, relative position and direction.

Figure 6-1 shows the navigation flowchart of the landmark-based system.

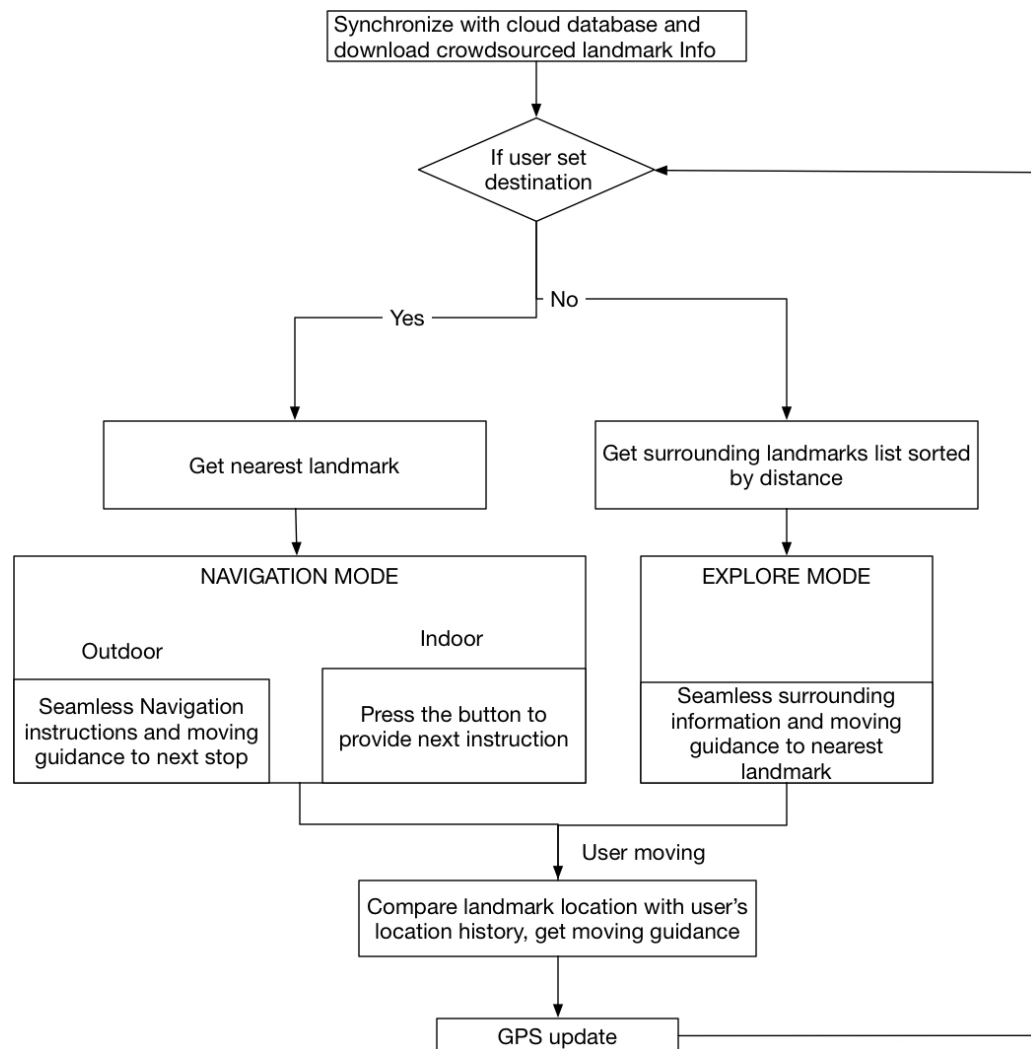


Figure 9: BVI Navigation flow chart

6.2 Outdoor Navigation Explore Mode

There are three parts of the provided information for BVI users exploring:

1. Surrounding landmarks and corresponding distances & orientation.
2. Nearest landmark and destination information.
3. Guidance for continued movement.

Once the BVI user application synchronizes with the cloud database, the app will compare the users' current GPS location with each landmark location to get a list of surrounding landmarks. If a user is moving, the application will record the user's most recent locations, and provide guidance of continued movement and navigation instructions based on their location history. All the information will be updated when the GPS location updates.

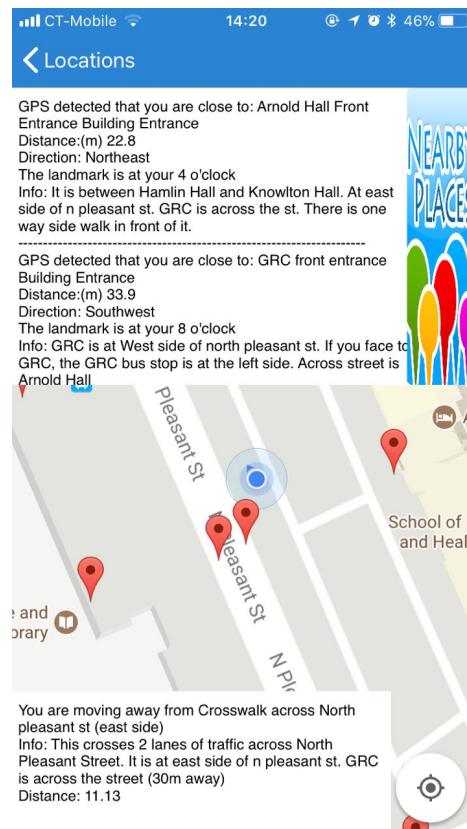


Figure 10: BVI Explore mode UI

6.2.1 Surrounding Landmarks List

The application provides surrounding landmarks and corresponding distances & orientation. The distance and orientation are calculated using longitude and latitude based on a spherical earth (ignoring ellipsoidal effects), which is accurate enough for most of purposes [13].

This application uses the “Haversine” formula to calculate the great-circle distance between two points; that is, the shortest distance over the earth’s surface - giving an ‘as-the-crow-flies’ distance between points.

Haversine formula: $a = \sin^2(\Delta\phi/2) + \cos \phi_1 \cdot \cos \phi_2 \cdot \sin^2(\Delta\lambda/2)$

$c = 2 * \text{atan2}(\sqrt{a}, \sqrt{1-a})$

$d = R * c$

where ϕ is latitude, λ is longitude, R is earth’s radius (mean radius = 6,371km).

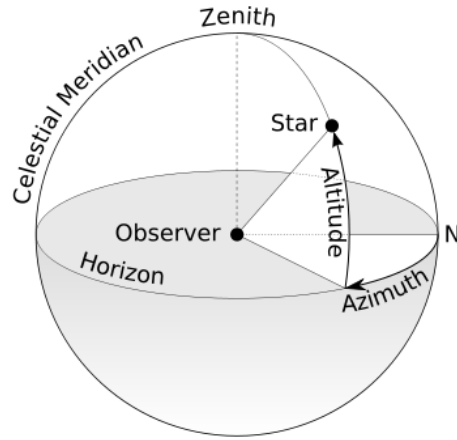


Figure 11: Distance calculation

For the bearing between 2 points, we use the formula:

$\Theta = \text{atan2}(\sin(\Delta\text{long}).\cos(\text{lat}_2), \cos(\text{lat}_1).\sin(\text{lat}_2) - \sin(\text{lat}_1).\cos(\text{lat}_2).\cos(\Delta\text{long}))$.

Therefore, we can calculate the orientation for the user based on the bearing Θ and user’s compass heading ω .

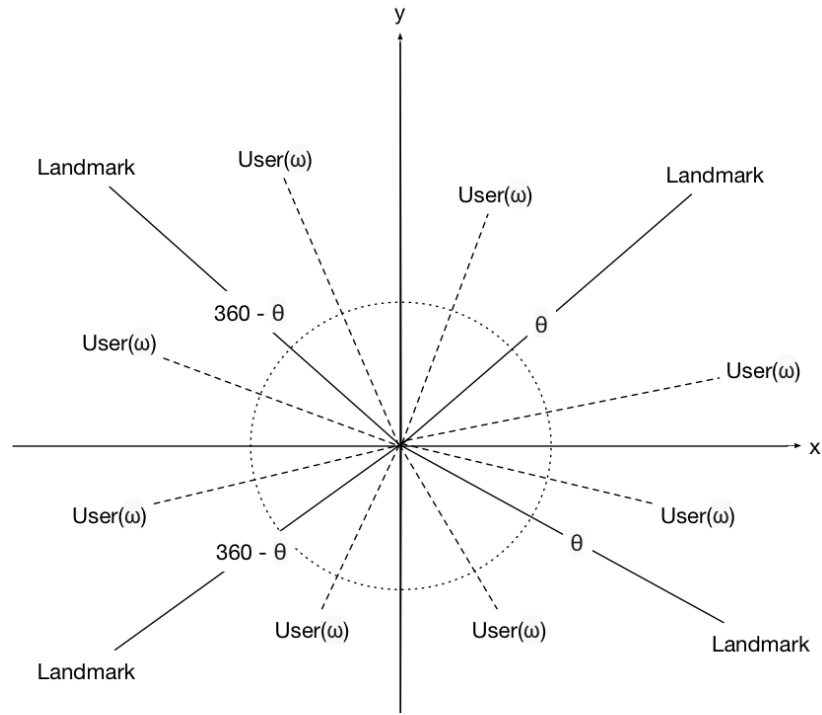


Figure 12: BVI Orientation calculation

Once the user's heading is updated, the orientation is also updated.

6.2.2 Contextual Information

In order to let BVI users get familiar with the environment, this application will provide navigational information such as nearby landmarks description and position relative to the nearest landmark and moving guidance. For example, for a crosswalk, this application can provide the direction and how many lanes it crosses, as well as there being a median in the middle.

The moving guidance can provide the relative direction of movement between users and the nearest landmark or destination. Thus, users can know if they are moving towards or moving away from the landmark. We maintain a K-size queue to save recent GPS locations. Once the location of the user is updated, the first location in the queue, which is the oldest one, will be compared with the current location and be removed from the queue. If the corresponding distance of the old location is farther than the current location, we know that the user is moving towards the destination. If users are moving towards the destination and the distance is less than 5 meters, users know that they are approaching the destination.

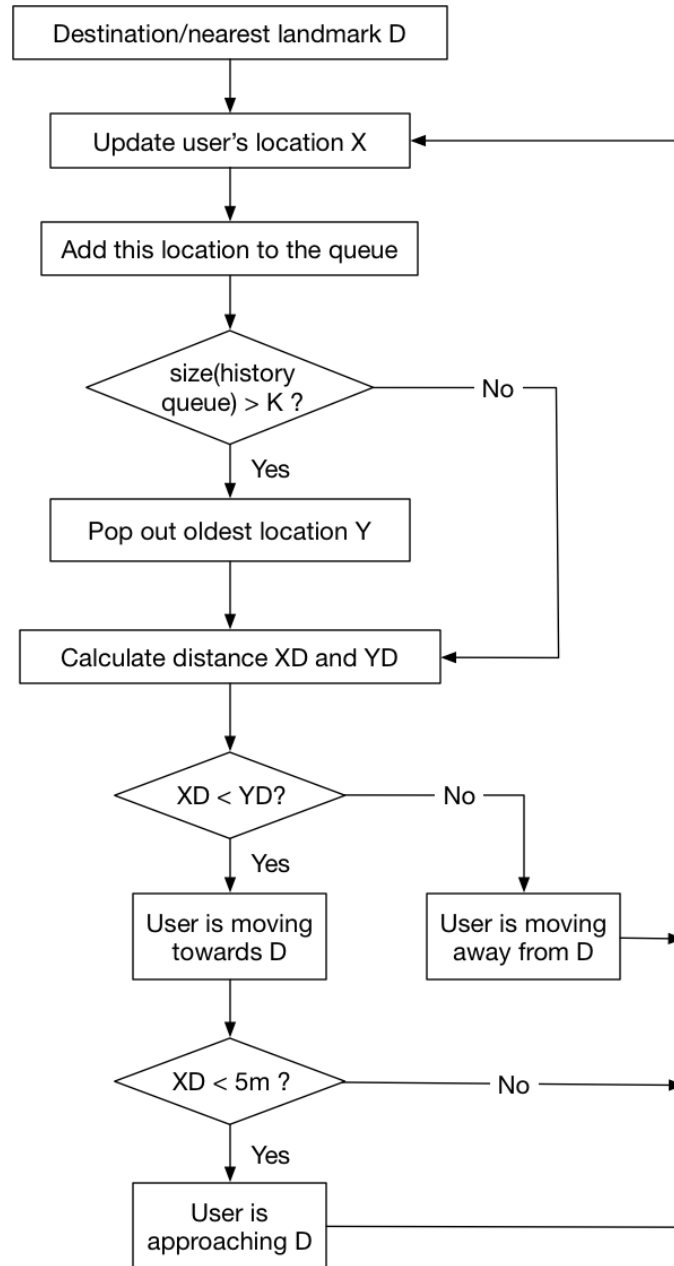


Figure 13: BVI Moving guidance flow chart

6.3 Outdoor Navigation Mode

Weights: The weight on each link indicates the degree of difficulty to travel through the link. In our system, since we only link the node that can be accessed, the weight is the distance between the end and start nodes of the link. For each landmark

node, we already have the corresponding latitude and longitude, so we can easily calculate the distance of each link.

We create a hash map to store the whole graph after downloading all the landmarks from the database. The key is the landmark node, and the value is an array of adjacent landmark nodes. We use Dijkstra's algorithm to find the shortest path between start landmark and destination.

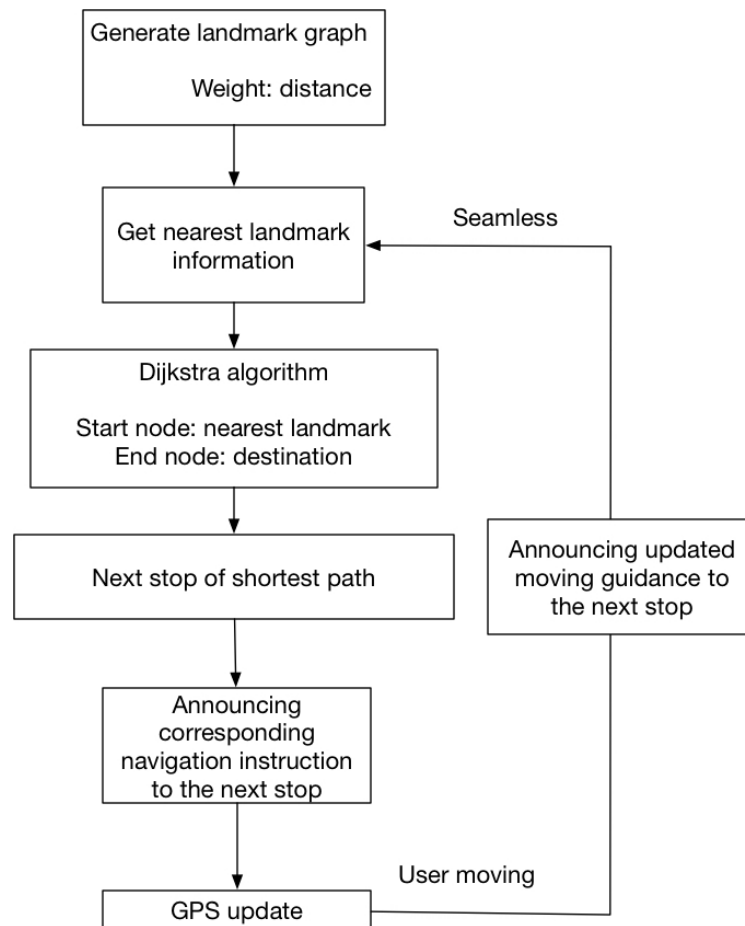


Figure 14: BVI Navigation flow chart

6.4 Indoor Navigation System

Bluetooth 4.0 low energy will be used for the indoor navigation system. It was first introduced under the name Wibree by Nokia in 2006 and became part of the main Bluetooth standard in 2010, the year Bluetooth Core Specification Version 4.0 was adopted [14]. Features of Bluetooth Low Energy wireless technology include: an ultra-low peak, the power consumption with average and idle modes, ability to run for years on standard coin-cell batteries, the low cost, the multi-vendor interoperability, and an enhanced range.

6.4.1 Bluetooth Tags Deployment

Our goal is to deploy at least three beacons for each point in a room to locate the users. The iBeacons, which can cover most possible users, would be selected. Thus, the most popular place will have more BLE coverage.

6.4.1.1 Algorithm outline

For each of the candidate beacon, its initial popularity N_p , the number of potential listeners that are within the candidate beacon's radio range and are not yet of 3-coverage, is first calculated. Then, each time a candidate beacon is selected if it has the greatest number of N_p . The deployment or selection process proceeds progressively and terminates when all listeners are at least of 3-coverage.

6.4.1.2 Algorithm Implementation

Algorithm 1. Beacon Deployment Algorithm

```
for each candidate beacon
    calculate its initial  $N_p$ 
set the coverage of each potential listener to be 0
put all candidate beacons in a list  $L_{cb}$ 
until the coverage of all potential listeners are at least 3
    sort  $L_{cb}$  with  $N_p$  in a non-increasing order
    select and delete a beacon from the head of the sorted
     $L_{cb}$ 
    update the coverage of the potential listeners that are
    covered by the selected beacon
    update the  $N_p$  in the  $L_{cb}$ 
output deployed positions of the selected beacons
```

Variable	Definition
Range	The coverage radius of the iBeacon
Size	Length and width of a room
Interval of the candidates iBeacons	The distance between each assumed iBeacons, that is, the candidates grid size
Interval of the assumed listeners	The distance between each assumed listeners, that is, the potential listeners grid size
N_p	the number of potential listeners that are within the candidate beacon's radio range and are not yet of 3-coverage
L_{cb}	List of candidates iBeacons

Table 7: Variable definition of Deployment Algorithm

6.4.1.3 Case study

Figure 6-7 shows the simulation of BLE deployment. X-axis and Y-axis are the length of the deploying area. The range of BLE is 1.5, the area size is 8*5, the interval of the candidates iBeacons is 1, the interval of the assumed listeners is 0.5.

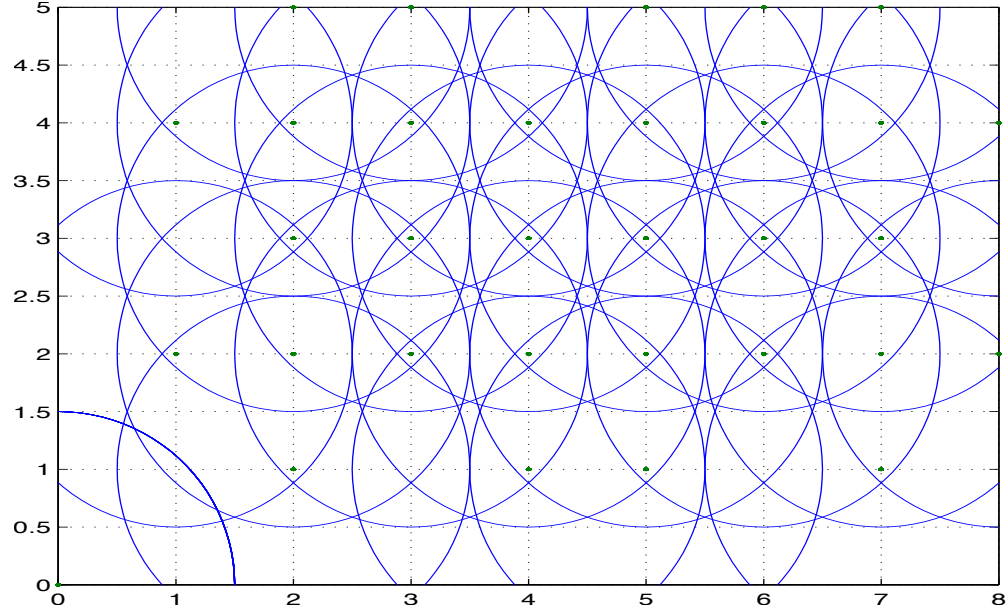


Figure 15: BLE Deployment case study

6.4.2 Distance Estimation

In order to obtain the distance between these two devices, we measure the RSSI signal emitted by the beacon, and received by iPhone. RSSI stands for received signal strength indication. It is a measurement of the power of a telecommunication signal, which is a Bluetooth signal in our case. An iPhone is able to measure an RSSI Bluetooth signal using the appropriate framework (CoreBluetooth & CoreLocation). The value is measured in dBm.

The formula below converts the distance into a RSSI signal:

$$RSSI(d) = RSSI(d_0) - 10 \times n \times \log\left(\frac{d}{d_0}\right)$$

Using $d_0 = 1$ meter, and solving equation above for d , the formula can be simplified to:

$$d = 10^{\frac{RSSI(d_0) - RSSI(d)}{10 \times n}}$$

6.4.3 Localization Methods

There are several methods to calculate the coordinates of a point using distances or angles. Triangulation, trilateration, multilateration are well-known methods. Whereas triangulation uses angles to compute the position of a point, trilateration works with distances. Trilateration is the one that is more appropriate for our project.

Trilateration is used to determine absolute or relative locations of points by measuring distances and using the geometry of circles, spheres, and triangles. This method has practical applications in surveying and navigation (GPS for example). We will use trilateration method for our indoor localization function.

Below an example of trilateration computation:

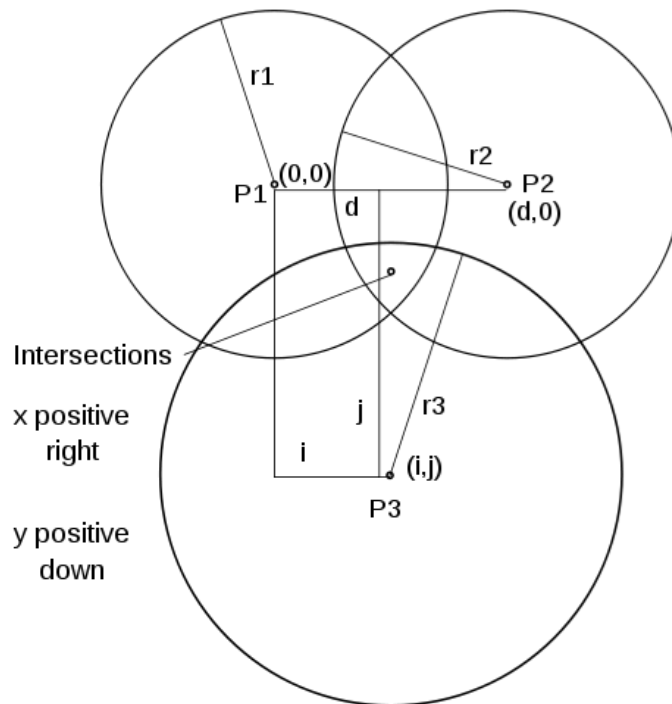


Figure 16: Trilateration Localization

$P1$, $P2$ and $P3$ can be assimilated as beacon devices. Their coordinates are known. $r1$, $r2$ and $r3$ are respectively the radius of $P1$, $P2$ and $P3$ spheres.

$$r_1^2 = x^2 + y^2 + z^2 \quad (1)$$

$$r_2^2 = (x - d)^2 + y^2 + z^2 \quad (2)$$

$$r_3^2 = (x - i)^2 + (y - j)^2 + z^2 \quad (3)$$

Solve x, (1) - (2):

$$x = \frac{r_1^2 - r_2^2 + d^2}{2 \times d}$$

Solve y, substituting the x equation back into (1):

$$r_1^2 = \frac{(r_1^2 - r_2^2 + d^2)^2}{4 \times d^2} + y^2 + z^2 \quad \text{or} \quad y^2 + z^2 = r_1^2 - \frac{(r_1^2 - r_2^2 + d^2)^2}{4 \times d^2},$$

where $z^2 = r_1^2 - x^2 - y^2$

$$\text{Then, } y = \frac{r_1^2 - r_3^2 + i^2 + j^2}{2 \times j} - \frac{i}{j} \times x$$

$$\text{Finally, } z = \pm \sqrt{r_1^2 - x^2 - y^2}$$

To sum up:

$$x = \frac{r_1^2 - r_2^2 + d^2}{2 \times d}, \quad y = \frac{r_1^2 - r_3^2 + i^2 + j^2}{2 \times j} - \frac{i}{j} \times x, \quad z = \pm \sqrt{r_1^2 - x^2 - y^2}$$

Thus, we have the (x,y,z) coordinates of the smartphone. We will not focus on the z-coordinate according to the project scope. However, it could be an extension of the thesis in the future and could reduce the number of beacons required and/or increase the accuracy.

6.4.4 Accuracy Improvement

Since BLE signal is not stable, the distance varies a lot using the RSSI to distance formula. In order to decrease the error, we use a sliding average filter to smooth the signal. Every time BLE is updated, we record the latest 5 signals and get the average

value. Since the average signal value for each iBeacon is required, we need to distinguish signals iPhone received. We use hash map to store the latest signal strength for each beacons. The key is beacon id, and the value is a queue, which stores most recent signals from this beacon. Every time the iPhone receives the signal, the queue should push in the signal value and pop out the oldest value.

Using the average could decrease the error significantly.

6.4.5 Switch between BLE and GPS Localization Method

When GPS accuracy is less than a specific value and the smartphone can receive more than three iBeacons signals (Rssi larger than specific value), the app will combine GPS localization with BLE localization using factor α . The positioning information by BLE is used to correct the error of GPS if the system can read BLE tags.

6.4.6 Indoor Navigation Method

Same to outdoor navigation, we use Dijkstra's algorithm to find the shortest path between start landmark and destination. The difference is for indoors, we need to press the button to get updated instructions instead of seamless instructions. That is because BLE signal is not stable, and the average value filter requires user to stay for a second to obtain stable average value, this delay might cause disorientation if instructions are updated seamlessly to users. Therefore, we use the button to make the navigation more accurate and clear.

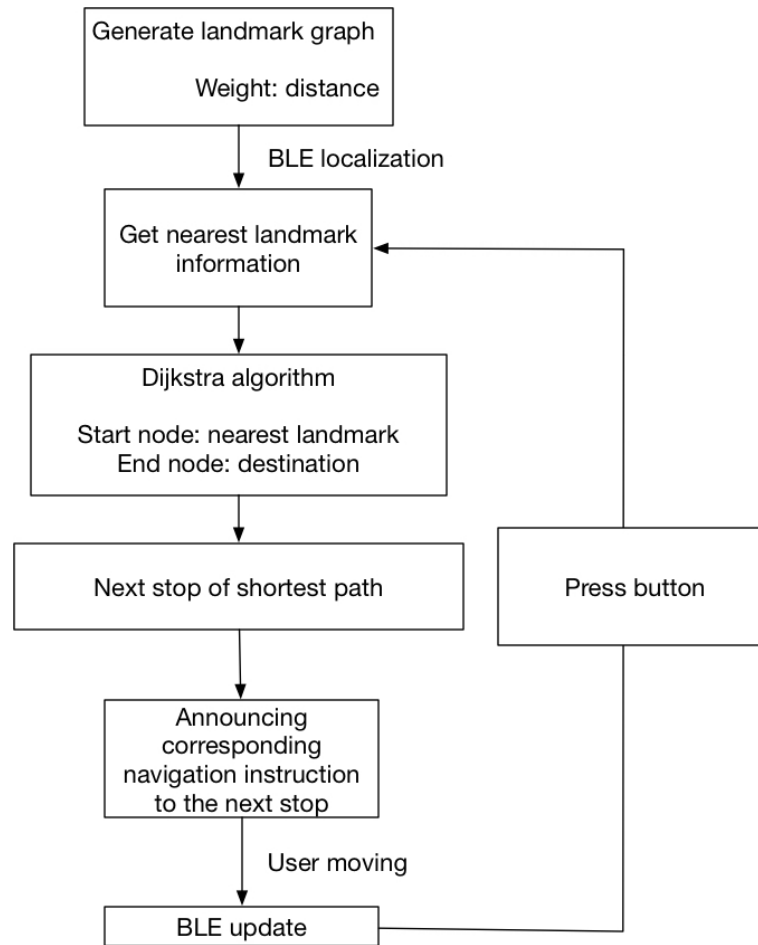


Figure 17: Indoor navigation flow chart

6.4.7 Switch between BLE and GPS Navigation Method

When entering indoor environment, the app will indicate to user that they have to press the instruction button to receive next instructions. The User interface changes slightly from outdoors where instructions are provided seamless to indoors where instructions are provided when pressing instruction button. This simple prompt informs the user of this change. And the voice over function will focus on the instruction button appeared automatically. Users can simply double tap the button to get the updated navigation instructions.

6.4 Accessible User Interface

Blind users can access these applications through a touchscreen since the applications interact with the user using accessibility features provided by the IOS operating system. Therefore, to enable blind users to access our application we designed the interface using accessibility features. “Voice Over” is the main Accessibility Service used on IOS to facilitate a vision-free use of the device. There are two ways to utilize voice over: 1. Touching the screen to highlight the visual component you are touching, and. 2. Swiping gesture that moves a cursor to highlight visual components on the screen. This method of highlighting is called hovering. When a visual component is hovered, it can be selected by double tapping the screen. For our system, users have following interactions:

- *Choose destination*: Swiping gesture and listen to voice over, double tap to select the destination
- *Navigation*: For outdoors the navigation instructions are provided seamlessly so users don’t need to interact with the phone. For indoors, there will be an instruction button appeared and the cursor to highlight visual components will automatically focus on the button. Therefor BVI users just need to double tap the screen to listen to navigation instructions.

6.5 Find Me

When blind users get lost or need help, they can use “Find Me” of the BVI users app for assistance. “Find Me” can configure the smart phone as a virtual BLE with specific UUID and major Id. The BLE signal contains the phone number of users.

Therefore, if there are volunteers nearby, they can use the volunteer application to search for BVI users who need help. Once BVI users send out BLE signals, their phone number and proximity will appear in the list in volunteer app.

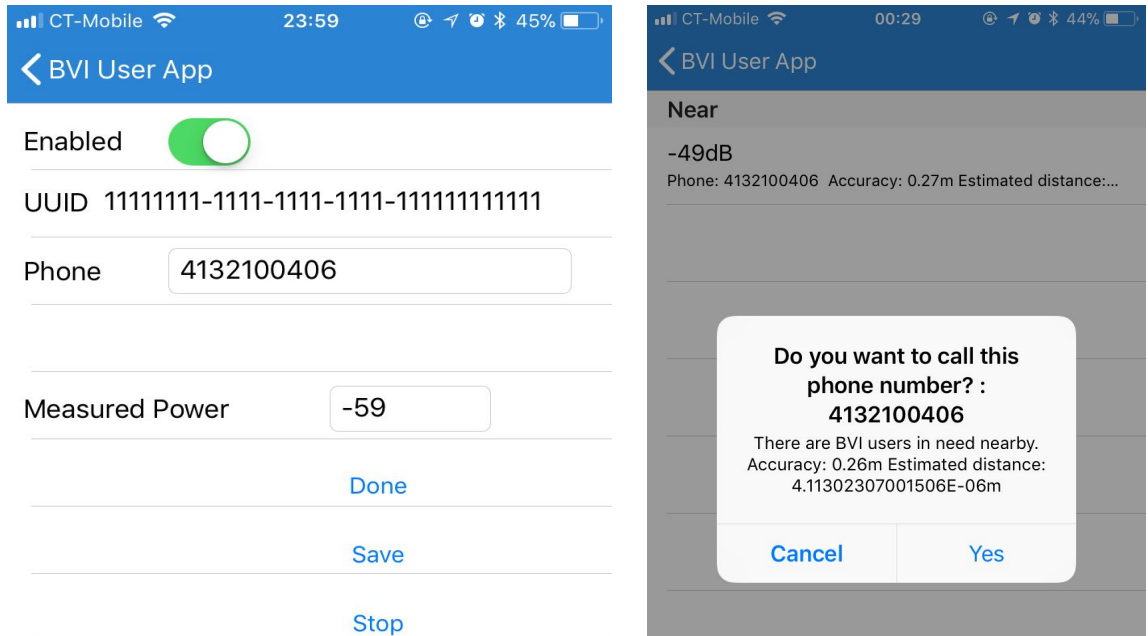


Figure 18: Find me screen shot

CHAPTER 7

FINAL DEMO

7.1 Offline Reports and Validation

We test out application near the UMASS campus roundabout.



Figure 19: UMASS roundabout

In this section of this chapter, we will test the function of this module.

1. Verify if volunteers can select location on the map and submit reports usefully using report app.
2. Verify if engineers can review volunteer's reports and call volunteers using admin app.
3. Verify if engineers can delete reports after updating the landmark database.
4. Verify if engineers can create, delete or modify existing landmarks.
5. Verify if volunteers can view verified landmarks' information.

As we can see from Fig 14 – 18, all the tests are passed.

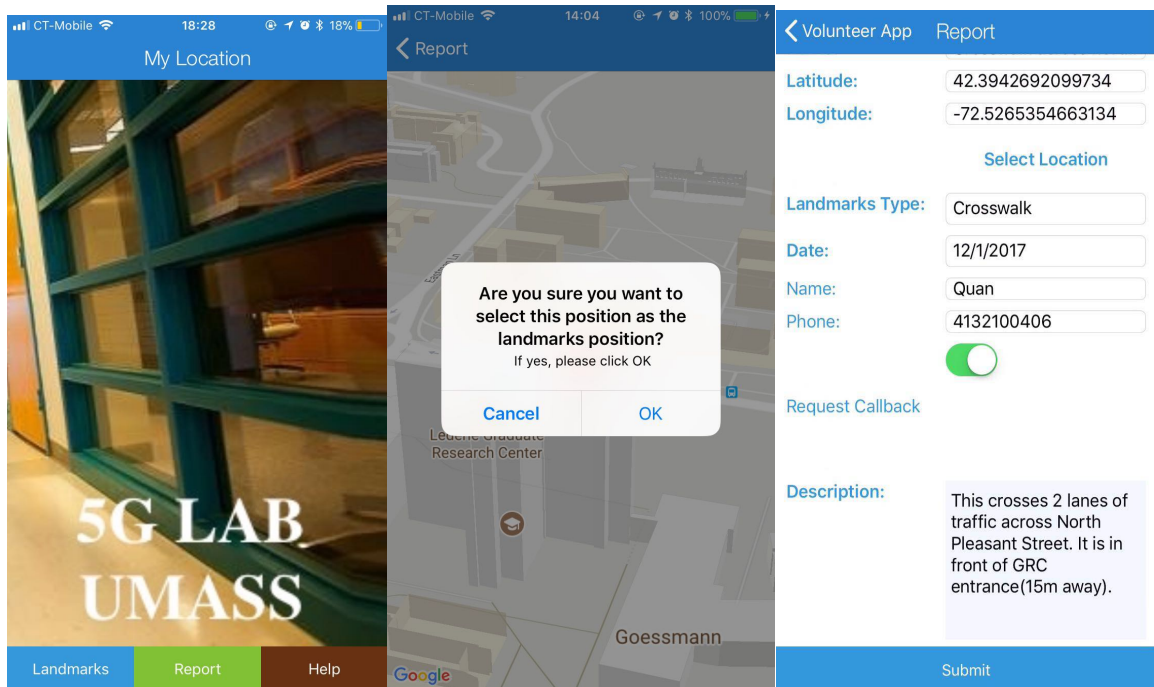


Figure 20: TEST submit report

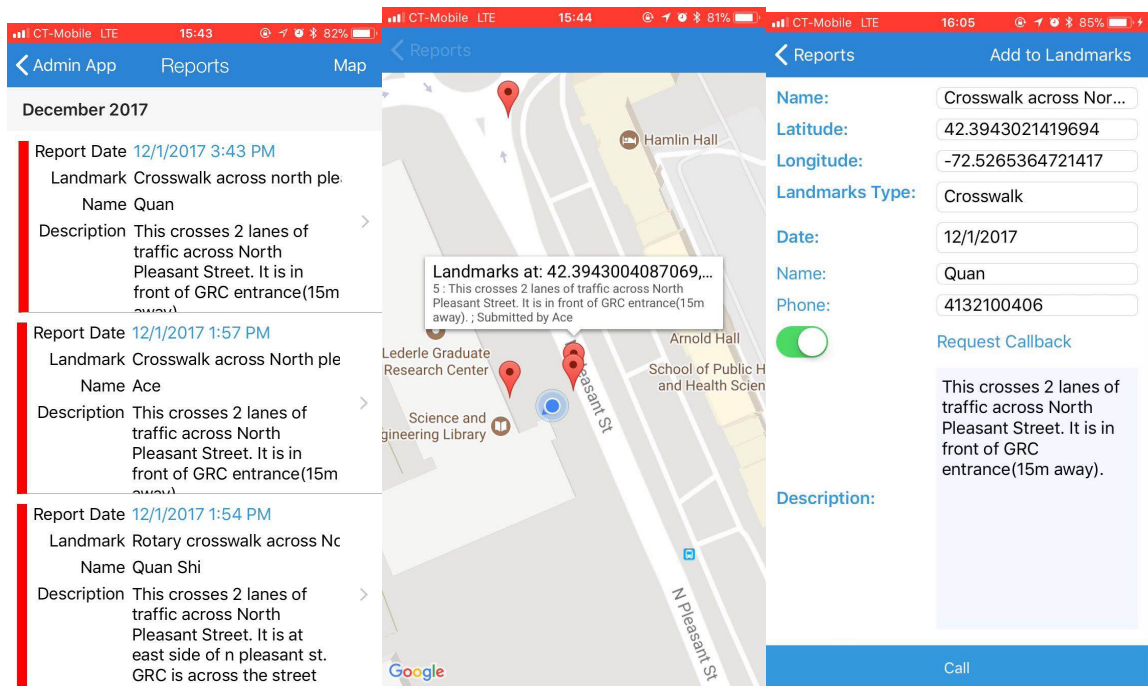


Figure 21: TEST review report

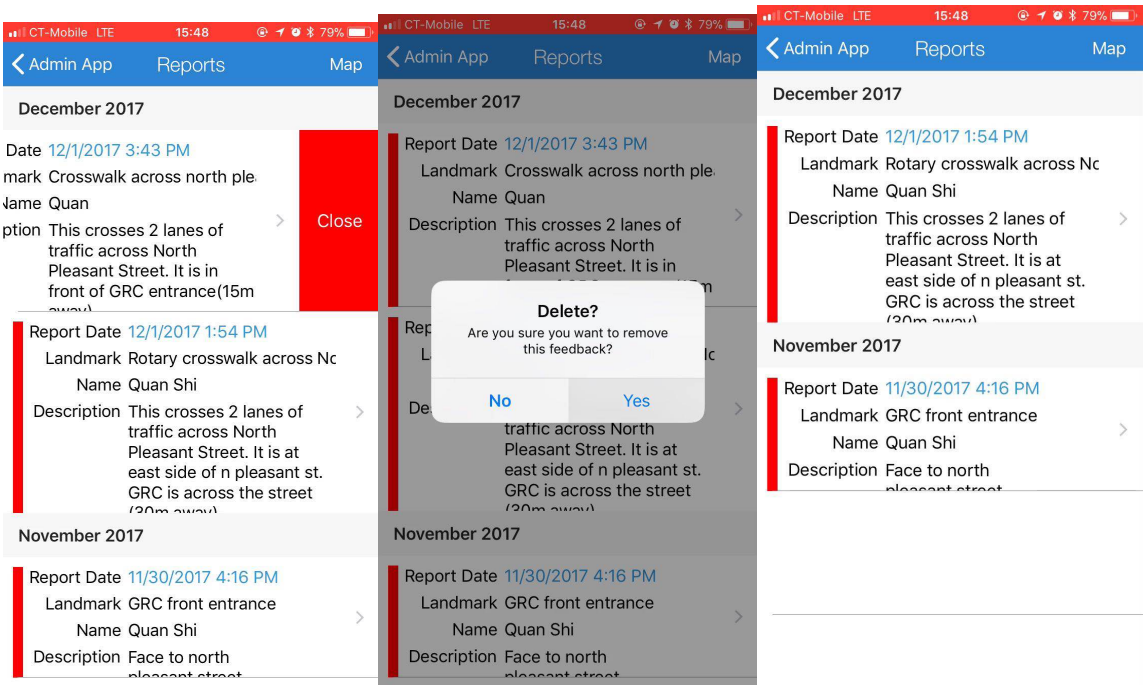


Figure 22: TEST delete report

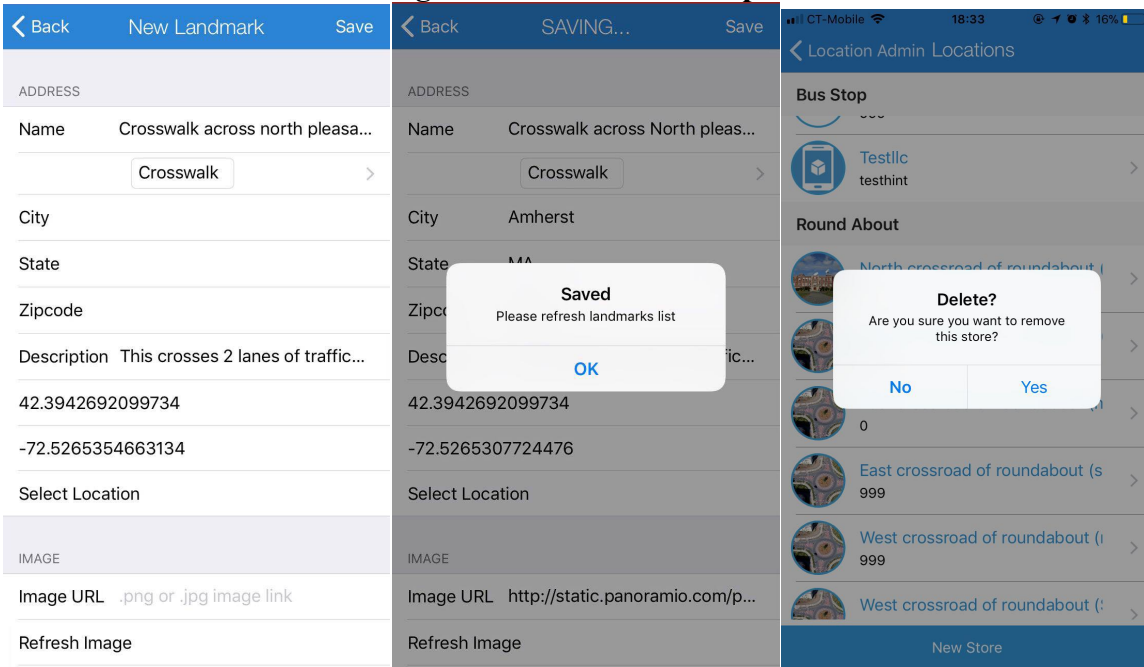


Figure 23: TEST update landmarks

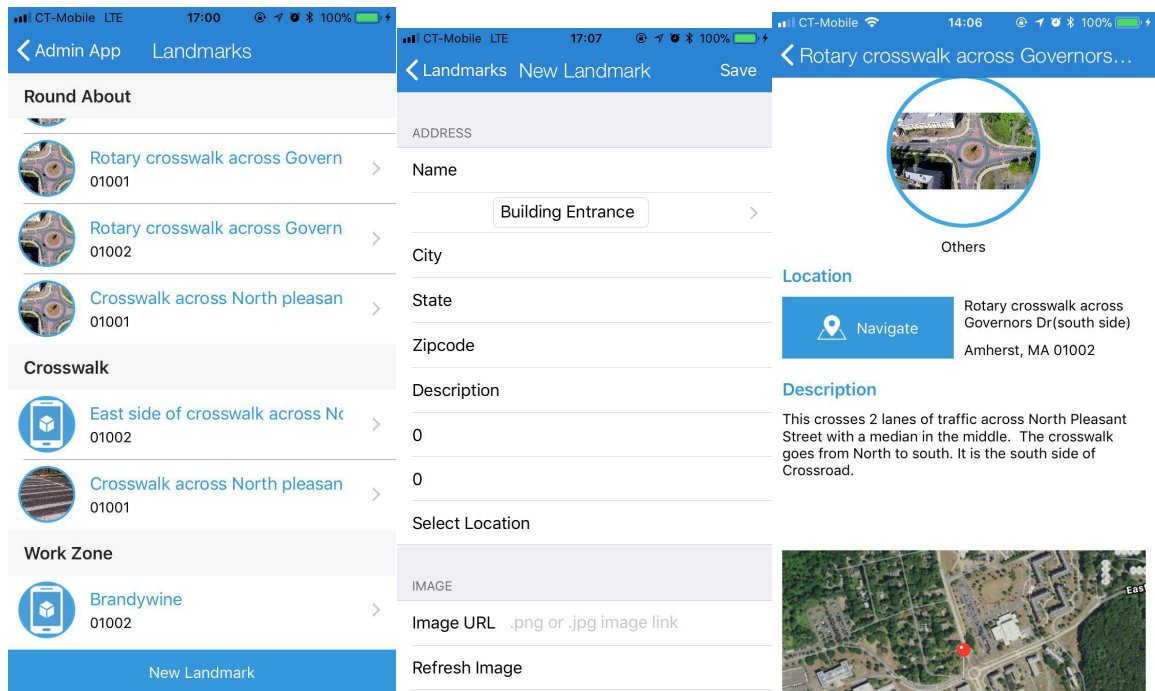


Figure 24: TEST review landmarks

From the above test, we verified that landmarks can be reported by volunteers and validated by engineers. Figure 19 is the landmarks map of the UMASS Roundabout.

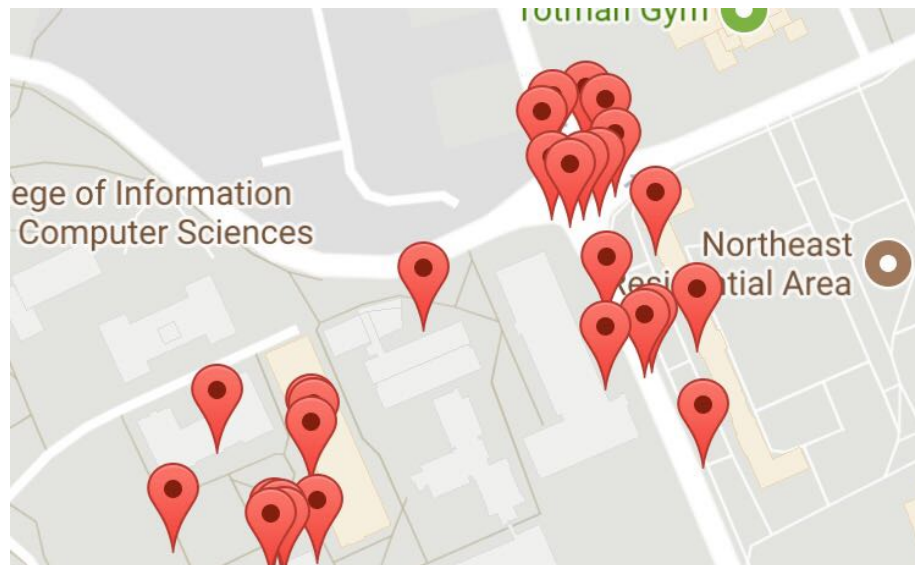


Figure 25: Landmarks Map

7.2 BLE Tags Deployment

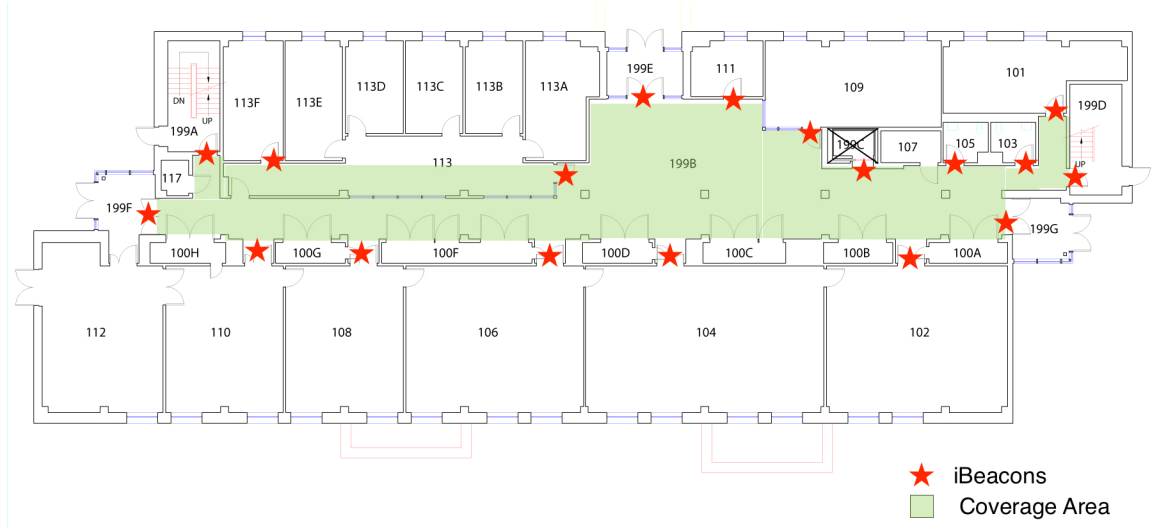


Figure 26: DEMO BLE deployment in KEB

7.3 Real Time Navigation

navigation mode:



Figure 27: DEMO navigation route

we test the app from the UMass rotary to Knowles Engineering Building. Users can use Voice Over and simple gesture to choose the destination and get navigation instructions.

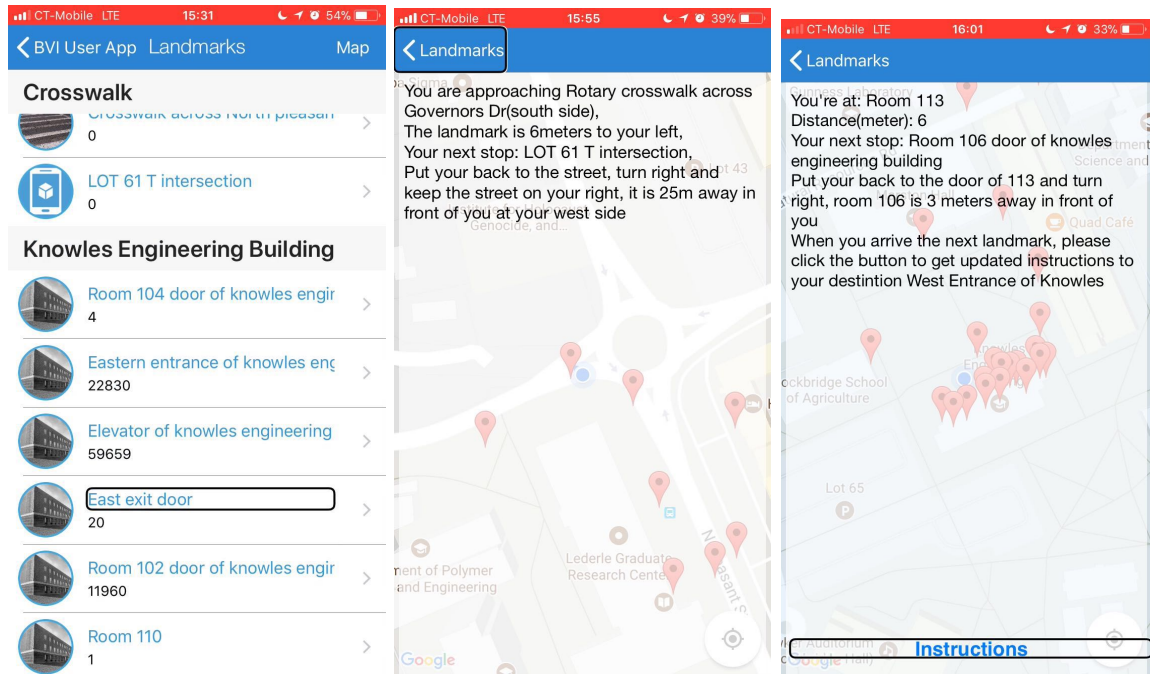


Figure 28: DEMO Destination mode navigation

If users do not set up the destination, the application will track the nearest destination and provide users the moving guidance to this landmark. Fig 21 shows the non-destination demo.

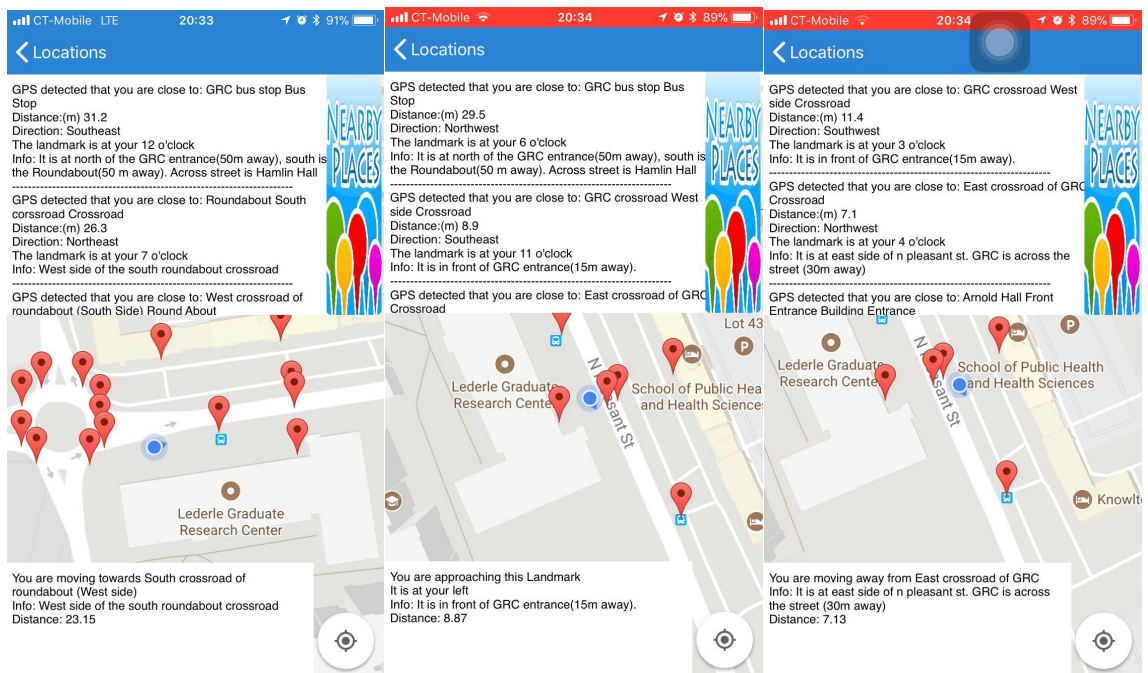


Figure 29: DEMO Non-estimation mode navigation

If users click the nearest button, a pop up with the nearest landmark information will display on the screen.

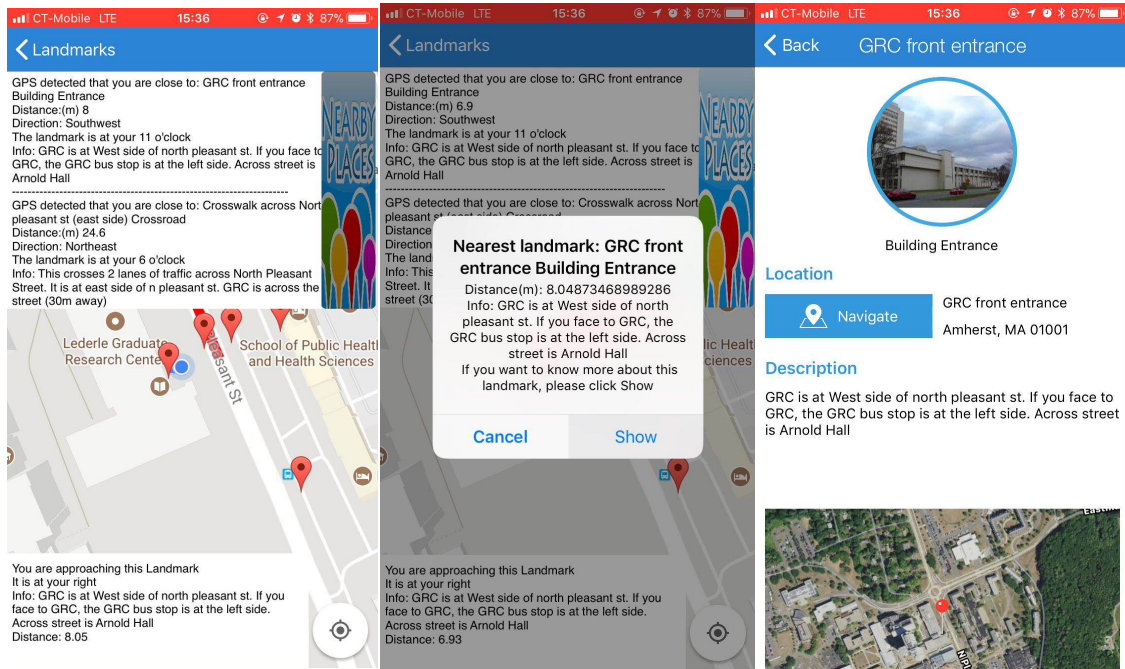


Figure 30: DEMO Nearest landmark

CHAPTER 8

CONCLUSION AND FUTURE WORK

In this thesis, we introduce the micro navigation system that will help BVI users navigate and explore environments. From the final demo walking from UMass rotary to KEB building, we can conclude that BVI users can get accurate step-by-step navigation instructions by audio to the destination selected in indoor and outdoor environment. The localization error is less than 2.5 meters indoors. Our future work involves improving the UI accessibility for BVI users. Currently BVI users need to swipe the list, listen to each landmark name and select the destination. In the future, we will design the text to speech feature helping BVI users better using our app. Moreover, we will consider more situation for the weights define, such as the route between two landmarks is hard for BVI to pass. We will use a new parameter to represent the difficulty passing the link, and we will define the weight by this new parameter and distance.

For the future work, we will add auto-validation feature to reduce the workload of admin if there are thousands reports to review. We can mark the report as valid if more than 10 people are describing same place, and for outdoor landmarks we could verify it using Google places API.

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