Indoor Localization using Wireless Access Points in the Physical Sciences Building, University of the Philippines Los Baños

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***Abstract*— As people spend more time indoors and as door-to-door delivery services become more prevalent, there is a need for people to see their location and to navigate indoors. Due to obstructions, GPS results to unreliable location approximation and there is no existing mapping up to the room-level. With that, a user application was developed in order to compute the user's location and to aid the user in navigation which made use of existing Wi-Fi infrastructure within the specified building. While getting the current location resulted to a high error, the pathfinder is still able to accurately show the optimal path by inputting room names.**

***Index Terms*— localization, trilateration, geocoding, dead-reckoning**

I. Introduction

A. Background of the Study

Global Navigation Satellite Systems (GNSS) such as Global Positioning System (GPS) has been extensively used by individuals and businesses today. According to European GNSS Agency [1], "Global Navigation Satellite System (GNSS) refers to a constellation of satellites providing signals from space that transmit positioning and timing data to GNSS receivers." The receivers then use this data to determine the location. GPS is one of the common features of today's smartphones where it could be easily used. Many services focus on the usage of GPS in real life such as web mapping services, ride-hailing and ride-sharing services, and logistics services.

Starting the late 1990's, there became a wide availability and significant advancement of the GPS technology [2]. As the technology is commonly used for outdoor positioning, there is also demand and benefits to having the ability to locate indoors. However if the usage is concerned with indoor localization, there is a limitation with GPS. There is a poor capacity to receive the satellites' signals indoors leading to an inaccurate positioning that is needed for room-level or indoor-level tracking. Additionally, Roger McKinlay, a navigation specialist and former president of the UK Royal Institute of Navigation was interviewed in [3] where he stated that GPS signals are weak indoors, and the receivers cannot get the amount of signals they need– hence other forms of localization are needed. Thus, a system has to be created in order to achieve indoor localization. Accordingly, Lemmens [4] stated that, "Indoor Positioning System (IPS) is a system of network connected devices which is used for wireless locationing of objects and persons inside buildings and partly covered areas".

There is abundant research revolving the indoor localization methods and technologies. Some of these technologies are Bluetooth technology, Wi-Fi positioning system, Geomagnetic technology, Visual Light Communication, Near Field Communication, and Radio Frequency Identification. Accordingly, standard, low-cost, and already deployed technologies are also the trend for indoor tracking [5]. A research that focused on the analysis of IPS has mentioned that the most prevalent is the usage of Wi-Fi as it is used since the start of the indoor positioning [2]. There are other researches and companies which incorporate different methods, or "hybrid systems" [3].

According to [6], the indoor location market is expected to be worth 40.99 billion USD in 2022. Undeniably, researchers and companies are further researching to achieve indoor localization as humans spend more time indoors such as buildings, malls, hospitals, etc. More importantly, there are humans with special needs such as the elderly, kids, patients, and PWDs who will definitely benefit with IPS.

B. Statement of the Problem

Currently, one could only use GPS to estimate their location indoors. However, due to obstructions, the location shown in known applications like Google Maps are greatly unreliable and there is no existing mapping up to the room-level. Hence, there is a need to create an alternative to GPS for people to see their location indoors using existing Wi-Fi technologies which could also aid them in navigation.

C. Objectives

Generally, this study aims to develop an Android application that will show the indoor location of the user and will assist with navigation in the Physical Sciences Building, University of the Philippines Los Baños, College, Laguna.

Specifically, it aims:

1) to create an indoor map with the location of the access points;
2) to receive and process the data received from the user in order to compute and show his current location;
3) to receive input of the user's source and destination and show path for navigation; and

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4) to evaluate the effectiveness of the application in determining the user's location.

D. Significance of the Study

This study can assist humans and robots for indoor tracking and indoor navigation. Indoor localization is useful for delivery logistics, inventory or items tracking, human tracking, indoor navigation, etc. For example, delivery services are becoming more prevalent nowadays, due to the rise of online shopping and food deliveries. The difficulty would be to have an actual door-to-door delivery in a building unit such as condominium or commercial spaces where there are numerous units in the said building. Another example would be the usage for human tracking, some examples are for visually impaired individuals, children, elderly, or patients inside a hospital. Aside from indoor tracking and navigation, it could also be used for location-based advertising and ambient intelligence [7].

E. Scope and Limitation of the Study

The focus of this study is to implement indoor localization using an Android mobile application in the F.O Santos (previously Physical Sciences) Building, University of the Philippines Los Baños, College, Laguna. Aside from Android, other operating systems will not be supported in the development due to the unavailability of resources that can be utilized by the researcher and due to the time constraints of the development and testing. The existing wireless access points of the said building of interest in the university will also be utilized for localization. Additionally, other built-in sensors from the Android phone will be utilized to further help with the computation of approximate location, such as accelerometer.

II. Review of Related Literature

Global Positioning System (GPS) technology has been improving constantly since it has been made available to the public [1]. However, one of its limitation is its capability to track the location of a user indoors or also called indoor localization due to obstacles like construction materials [7].

A. Use cases of Indoor Localization/Positioning

Gaining the ability to accurately track the location indoors are beneficial for delivery logistics, inventory tracking, human tracking, indoor navigation for humans and robots, etc. For example, delivery services are becoming more prevalent nowadays, due to the rise of online shopping and food deliveries. The difficulty would be to have an actual door-to-door delivery in a building unit such as condominium or commercial spaces where there are a number of units in one building. Another example would be the usage for human tracking, some examples are for children, elderly, or patients inside the hospital. More concrete examples would be firstly, it could help a user in navigating inside a shopping center or a hospital; secondly, it could help in marketing analysis by tracking the more frequently visited parts of shopping centers; thirdly, it could help a user navigate to a specific doctor's office; lastly, for example medical equipment, can be located easily in case of emergency [2].

B. Indoor Positioning System and its Topologies

Given the number of benefits and use cases of indoor localization, researchers have used different technologies and methodologies to address this problem–leading to another type of system called Indoor Positioning System or IPS. According to Lemmens [4], "Indoor Positioning System (IPS) is a system of network connected devices which is used for wireless locationing of objects and persons inside buildings and partly covered areas".

Another work by Liu & Darabi [8] also cited that there are four system topologies for a positioning system which are remote, self-positioning, indirect remote, and indirect self-positioning. For a remote positioning system, the signal transmitter is mobile while there are fixed units that receive its signal and the computation of position is done at a master station. Meanwhile, for a self-positioning system, the mobile device receives the signals from different locations and its location is computed on its own. As for an indirect remote system, the computation from the aforementioned system was delivered to the remote side; and lastly, if the computation was delivered to a mobile unit, then it is an indirect self-positioning system [8].

C. Indoor Localization Approaches

It is important to review other approaches that could be done to address localization as the concepts are often related whether indoor or outdoor. A notable statement by Kaluža, Beg, and Vukelić [2] is that "... the IPS system functions in the same way as the GPS for outdoor positioning. Instead of retrieving the satellite signal, the IPS exchanges signals between the location devices and smart devices' sensors." Thus, it cannot be denied that there is a huge similarity of concepts between GPS and IPS approaches, as well as within the IPS approaches.

Some of the systems for indoor localization use numerous technologies such as Bluetooth, Ultra-wideband (UWB), Wi-Fi, Radio Frequency Identification (RFID), Geomagnetic, lights, and others [2], [5]. Bluetooth low energy (BLE) is one of the technologies used to address indoor localization. It does not require an external power source and as the name states, it has long battery life since it only uses low energy at a time. According to Blaz [9], the location of the user can be estimated by using the detected signals from the transmitter. Meanwhile, UWB is a type of radio technology which has been proven effective according to Alarifi, et al. [10]. Data is spread over a wide portion of the frequency spectrum leading to larger data transmission and low energy consumption [10]. Another technology is Radio Frequency Identification (RFID) which is commonly used today for access control as alternative to the traditional keys and electronic payments in expressway tolls and railway transportation systems (MRT and LRT). According to Bai, Wu, Wu, and Zhang [11], RFID system usually consists of tags, reader, host computer/infrastructure whereas the reader and the host computer are linked either wired or wirelessly. In terms of indoor localization, it could be firstly, tag-oriented whereas the focus is on locating RFID tags; and secondly, reader-oriented whereas the focus is to find the position of the readers [11].

Meanwhile, Geomagnetic technology is also popular among research due to the external hardware needed for the aforementioned approaches. Geomagnetic technology's rationale is similar to how animals orient themselves– through local anomalies of Earth's magnetic field [12]. To use geomagnetic field for indoor localization, it undergoes a process called location fingerprinting which has two phases: training which involves fingerprinting, and positioning [13]. In fingerprinting a database with the features or fingerprints of the scenario of the reference locations has to be created [5]. Li, et al. [13] stated that at the position to be determined, calculations are done and then it is later compared with information in the database. Another study by Bimal, Hwang and Pyun [14] also conducted a research using a smartphone device's magnetic sensor to utilize geomagnetic field for positioning and it was proven effective with a mean localization error in both of their cases of below two meters with a comparatively high maximum positioning error and deviation of error.

The usage of visible light communication (VLC) technologies for indoor localization is also promising as compared to other methodologies since it has a 0.1 to 0.35 meter positioning error as compared to other technologies with greater than one meter positioning error [15]. It also makes use of light-emitting diodes (LEDs) and for indoor localization, the data transmitted from the visible light signals are measured [10]. Similar to fingerprinting, these data includes features that are helpful in identifying the location.

Wi-Fi technologies are also used for indoor localization even at the start of indoor localization [2]. Since it uses pre-existing infrastructures, it also became one of the most commonly used technologies [16]. It also has similarities with other approaches as it uses a radio map that models the network of characteristics in a deployment area and this radio map is also used for positioning whereas the likely position is computed by the network of characteristics given [17]. While other research have stated that using Wi-Fi technologies result to a lower accuracy as compared to others, there are some recent studies who have proven that an accuracy of one centimeter can be achieved using this approach compared to GPS which can only accomplish 3-15 meter accuracy [18], [19]. The study mentioned that to achieve a centimeter accuracy, the problem of bandwidth limitation has to be addressed [18].

D. *Localization using Received Signal Strength*

According to Wi-Fi Location-Based Services 4.1 Design Guide by Cisco Systems Inc. [20], there are four basic categories of systems in determining position, or also known as Real Time Location Systems (RTLS). These are cell of origin, distance, angle, and location patterning. While there are different categories, it is also possible to implement the system with more than one category. Received signal strength (RSS) was used under the cell of origin category and distance category based on the said design guide.

Usage of the cell of origin technique is said to be one of the simplest methods which uses the associated access points in Wi-Fi 802.11 systems [20]. There have been variations with this approach but the simplest is getting the location of the user through the cell or access point the device has been registered. Since it could be registered to an access point that is not necessarily the closest to the user, additional methods are used. One way to improve this is to use the highest received signal strength indication (RSSI) to determine the nearest access point.

The next category discussed further by Cisco Systems Inc. [20] are distance-based or lateration techniques which included Received Signal Strength as another measurement. In this approach, RSS is measured by either the mobile device or the receiving sensor. The transmitter output power, cable losses, antenna gains, and the appropriate *path loss model* will allow the solution for the distance between the two stations involved. One common path loss model is [20],

$$PL = PL_{1Meter} + 10log(d^n) + s \tag{1}$$

In Equation 1,

- *PL* is the total *path loss* between the receiver and sender in dB. It is a value typically greater than or equal to zero.
- PL_{1Meter} is the *reference path loss* in dB for the desired frequency when the receiver-to-transmitter distance is 1 meter. It must be specified as a value greater than or equal to zero.
- *d* is the *distance* between the transmitter and receiver in meters.
- *n* is the *path loss exponent* for the environment.
- *s* is the standard deviation associated with the degree of *shadow fading* present in the environment, in dB. This must be specified as a value greater than or equal to zero.

Path loss is the level of the signal attenuation in the environment and it is the difference between the level of the transmitted signal [20]. Meanwhile, *path loss exponent* is the rate at which the path loss increases with the distance of the receiver and transmitter [20]. According to Cisco Systems Inc. [20], some of the common path loss exponents range from 2 for open free space to values greater than 2 in environments where obstructions are present. Additionally, it was mentioned that typical path loss exponent for an indoor office environment may be 3.5, a dense commercial or industrial environment 3.7 to 4.0 and a dense home environment could be as high as 4.5.

E. *Trilateration with Received Signal Strength*

Trilateration is a localization technique which finds the intersection between three circles centered at anchor as the position of node whereas there is an estimate distance between the node and at least three anchor nodes in a 2D plane [**?**]. This technique can be used with RSS and RSS multi-lateration can also be performed to further refine location accuracy [20].

Since RSS lateration is cost-effective as it does not need specialized hardware, it became very attractive from a cost-performance standpoint to designers of 802.11-based WLAN systems that wants to add positioning solutions [20]. Consequently, the interference from the environment has to be considered as a purely circular pattern cannot be achieved in real life [20].

F. Dead-reckoning Algorithm

According to Zhang, et al. [21], dead-reckoning algorithm is the process of approximating the current location given the previous location, time, speed, and direction of movement. It is also one of the most popular methods in inertial measurement unit positioning which utilizes devices like accelerometer, magnetometer, and gyroscope sensors [21]. If only the initial location is known, its performance heavily relies on the sensors' measurement accuracy thus, this suffers from accumulated measurement [22].

One common approach is through step events which uses step length to determine the distance and some form of directional data [23]. The step length could be an averaged value or an estimated value based on step frequency models which are built from previous data [23]. Meanwhile, step direction estimation is very challenging due to sensitivity to error in the sensor's orientation estimation [22].

As mentioned by [22], step counting is a well-known algorithm to approximate the displacement when the sensors are not placed on the foot. Moreover, step counting algorithm is constituted by step detection, step length estimation and step direction estimation [22]. One example of an improved approach to dead-reckoning [22] made use of map matching (MM) enhanced particle filter (PF) which alleviates the problem of accumulated errors. Another example [24] made use of knowledge based step length estimation.

III. Theoretical Framework

1) Received Signal Strength Indicator (RSSI):

As seen in equation 2, *RSSI* is the received signal strength indicator. d is the distance of the receiver from the transmitter. P_{tx} is the default transmit power of the router, or the signal strength at one meter. n is the path loss exponent. The value of n varies depending on the environment noise, however, there are some ranges of n that has been established for certain cases [20], [25].

$$RSSI = P_{tx} - 10 \times n \times log_{10}(d) \tag{2}$$

2) Trilateration:

Trilateration is a prevalent concept in GPS and this can also be used in indoor localization. The circles in Figure 1 signify the range of the omnidirectional transmission of the signals from the transmitters. These signals will intersect at one point or at an area which will become the approximation of the location of the user.

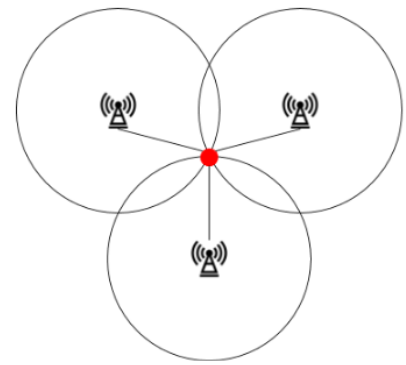

Fig. 1. Trilateration diagram

3) Dead-reckoning Algorithm:

Dead-reckoning algorithm is an approximation of the current location given the previous location, time, speed, and direction of movement [21] whereas a well-known algorithm to approximate the displacement when the sensors are not placed on the foot is step counting which is constituted by step detection, step length estimation and step direction estimation [22].

Moreover, the basic idea of the step-based DR tracking estimates current step displacement vector to the previously estimated location [26] which is,

$$l_k = l_{k-1} + s_k, \tag{3}$$

where l_{k-1} and l_k are the location estimates before and after the kth step, respectively. s_k is the estimated displacement vector for the kth step which is computed as,

$$s_k = [\rho_k cos\theta_k, \rho_k sin\theta_k]^T, \tag{4}$$

where ρ_k and ϑ_k are the stride length and heading orientation for the kth step, respectively.

4) Geocoding:

The process of addresses (human-readable address) being converted into geographic coordinates (latitude and longitude) is called geocoding while reverse geocoding is the opposite of the said process [27] or the location expressed in natural language [8]. This is used in routing or path finding services like Google Maps and Waze.

5) Mean squared Error (MSE):

Mean Squared Error (MSE) is calculated by the mean of the errors that have been squared as it relates to a function which is often a regression line [28]. It is defined by the equation:

$$MSE = \sum_{i=1}^{n} \frac{Y - \hat{Y}_i}{n} \tag{5}$$

For the negative values to not cancel positive values, the difference is squared before the mean is taken. With this, the smaller the MSE, the closer the fit is to the data [29] and it is often used in machine learning and in problems where the lack of precision should be quantified [28].

IV. Methodology

A. System Design

1) Materials: The user application is an Android application which was developed with Java using Android Studio 3.2.1 and the admin application was developed with React JS. SQLite was used for the local database of the user application which was used to store data more frequently and Firebase was used for both the user and admin application.

The blueprints and the location of the access points were mapped and translated to SVG files with feet as the unit of measurement using Inkscape 0.92.4.

The user application was also developed and tested on an Android phone with the following specifications:

- Model: Asus Zenfone 4 Selfie Lite
- Android Version: 7.1.1
- CPU: Qualcomm® Snapdragon™ 425 Mobile Platform with 64-bit Quad-core Processor 1.4 GHz
- GPU: Qualcomm® Adreno™ 308
- RAM: LPDDR3 2GB
- GPS Version: MPSS.JO.3.0-00239-8937_GENNS_PACK-1.92851.1.100222.1
- Wi-Fi and Bluetooth Version: CNSS.PR.4.0-00352-M8953BAAAANAZW-1*
- Cellular Network: Globe 4G / LTE
- Wireless technology: 802.11 b/g/n, Bluetooth 4.1, Wi-Fi Direct

Meanwhile, the existing access points in the Physical Sciences building has the following Wi-Fi specifications [30]:

Wi-Fi

- Wi-Fi Standards: IEEE 802.11a/b/g/n/ac
- Supported Rates:
  - 802.11ac: 6.5 to 867Mbps (MCS0 to MCS9, NSS = 1 to 2 for VHT20/40/80)
  - 802.11n: 6.5 Mbps to 300Mbps (MCS0 to MCS15)
  - 802.11a/g: 54, 48, 36, 24, 18, 12, 9 , 6Mbps
  - 802.11b: 11, 5.5, 2 and 1 Mbps
- Supported Channels:
  - 2.4GHz: 1-13
  - 5GHz: 36-64, 100-144, 149-165
- MIMO: 2X2 SU-MIMO
- Spatial Streams: 2 SU-MIMO
- Channelization: 20, 40, 80MHZ
- Security:
  - WPA-PSK, WPA-TKIP, WPA2 AES, 802.11i, Dynamic PSK
  - WIPS/WIDS
- Other Wi-Fi Features:
  - WMM, Power Save, Tx Beamforming, LDPC, STBC, 802.11r/k/v
  - Hotspot
  - Hotspot 2.0
  - Captive Portal
  - WISPr

And the existing access points also has the following RF specifications [30]:

RF

- Antenna Type:
  - BeamFlex+ adaptive antennas with polarization diversity
  - Adaptive antenna that provides up to 64 unique antenna patterns per band
- Antenna Gain (max): up to 4dBi
- Peak transmit power (aggregate across MIMO chains):
  - 2.4GHz: 22dBm
  - 5GHz: 22dBm
- Minimum Receive Sensitivity (which varies by band, channel width and MCS rate): -100 dBm
- Frequency Bands:
  - ISM (2.4-2.484GHz)
  - U-NII-1 (5.15-5.25GHz)
  - U-NII-2A (5.25-5.35GHz)
  - U-NII-2C (5.47-5.725GHz)
  - U-NII-3 (5.725-5.85GHz

2) User Types: The system has two types of user: system administrator and normal user. The normal user can only use the mobile user application. Through the user application, normal users have the following capabilities:

- Track their own location
- Get the route towards a destination
- By manually inputting a source location
- By localization to automatically input a source location
- Keep their location history
- Submit a bug report

Meanwhile, the system administrator also has the same capabilities of the normal user, but has the following additional capabilities:

- View the current location of the users
- Handle the map information
- Add additional map information
- Edit map information
- Delete map information
- Handle bug reports

B. Implementation

The implementation phases were divided into parts: the indoor map, the user application, and the admin application.

1) Indoor Map:

Before proceeding to the actual process of indoor localization, an indoor map was created which contains the rooms with its symbolic location or the location expressed in natural language [8] and the wireless access points in the building. With that, blueprints were requested from University Planning and Maintenance Office (UPMO) while the information about the access points in the Physical Sciences Building were requested from Information Technology Center (ITC). The blueprints given were broken down into parts: by wing and by floor.

Since parts of the blueprints were outdated, and there were differences in the units of measurement, the researcher created the maps by manually translating the blueprint to SVG files using Inkscape, with feet as the unit of measurement. To simplify the map generation, the rooms and hallways were represented with rectangles.

Meanwhile, the information about the access points only consisted of the MAC Addresses and the approximate location of the access points so the researcher also manually scanned and translated its location and floor on the created maps.

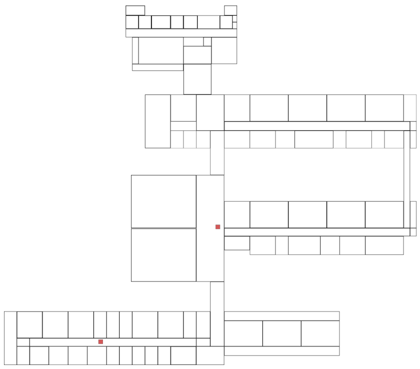

Fig. 2. First Floor Map

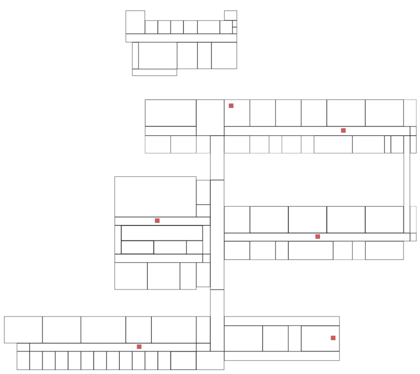

Fig. 3. Second Floor Map

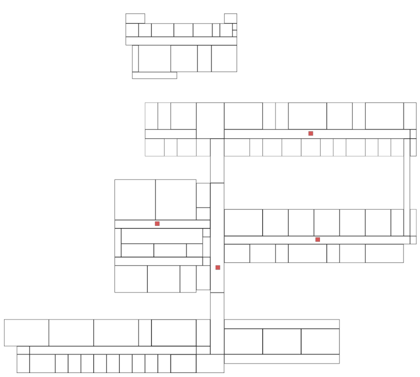

Fig. 4. Third Floor Map

Below is an example of how each area is represented.

```
Polygon {
name: "wing-b-path",
 floor: 2,
 height: 94.056,
 width: 12,
 center: [183.0, 192.443],
 corners: {
     [177.00, 145.415],
     [177.00, 239.471],
     [189.00, 145.415],
     [189.00, 239.471]
 }
}
```

Below is the list of the information about the access points in the Physical Sciences Building.

Name	MAC Address	X	Y
GF PhySci Wing B Corridor	24:79:2a:xx:xx:xx	183	189.915
GF ICS Hallway	0c:f4:d5:xx:xx:xx	82.5	288.415
2F ICS Megahall	0c:f4:d5:xx:xx:xx	131	180.24
2F Physics Faculty Office	0c:f4:d5:xx:xx:xx	282	280.915
2F Physics Faculty Hallway	0c:f4:d5:xx:xx:xx	115.5	288.415
2F Chem Director's Office	0c:f4:d5:xx:xx:xx	194.5	81.665
2F Chem Director Hallway	0c:f4:d5:xx:xx:xx	290.75	102.915
2F Chemistry Lab Corridor	0c:f4:d5:xx:xx:xx	268.75	193.915
3F ICS	0c:f4:d5:xx:xx:xx	131	180.24
3F Chemistry Laboratory Corridor	0c:f4:d5:xx:xx:xx	350	150
3F Physci Hallway	0c:f4:d5:xx:xx:xx	183	217.915
3F Research Lab	0c:f4:d5:xx:xx:xx	268.75	193.915
3F ACED	0c:f4:d5:xx:xx:xx	262.75	102.915

TABLE I

ACCESS POINTS INFORMATION

2) User Application: The user application was used to 1. to receive and process the data in order to compute and show the user's current location and 2. to receive user's input of source and destination and show path for navigation.

For number 1, it is summarized as follows:

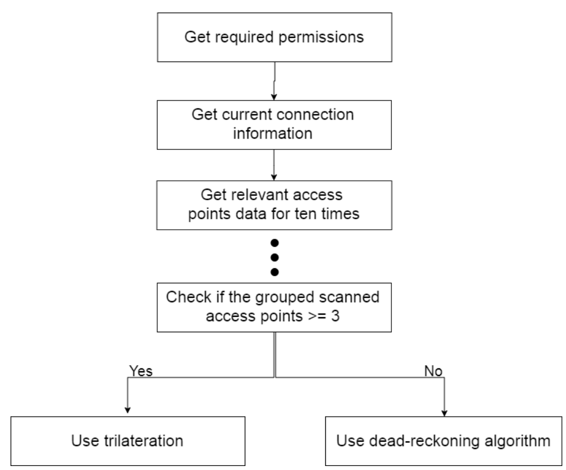

Fig. 5. Get Location Workflow

1) Get required permissions. The application requires the location permissions and the Wi-Fi connection to be enabled. This is only done the first time the application was run.
2) Get current connection information. Since the scope of the application is only in the Physical Sciences building, only the access points from the database is allowed. Therefore, the application does not run when the user is not connected to any of the said access points.

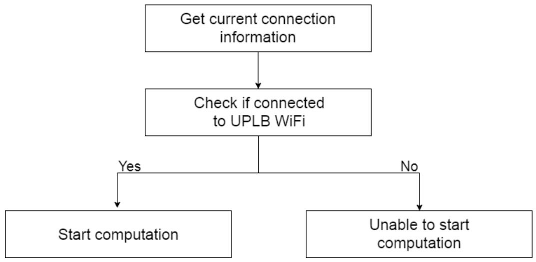

Fig. 6. Current Connection Workflow

3) Get relevant access points data for ten times. This is done prior to the computation which will later determine whether trilateration is possible or not.
The scanned access point are then filtered, to only include the access points which are stored in the database. Afterwards, these are grouped and averaged according to their MAC Addresses, and if there are at least three access points, trilateration is possible.

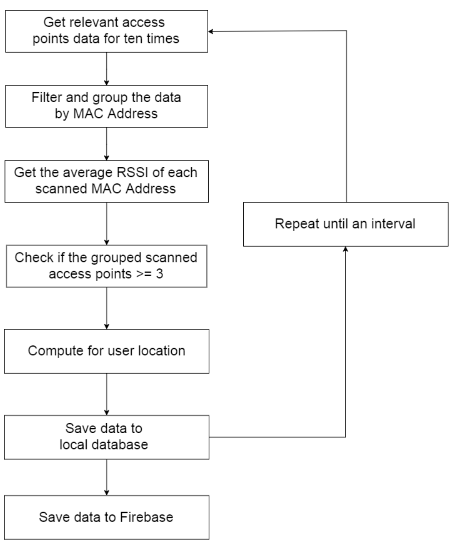

Fig. 7. Implementation Workflow

4) Get user location. This can be done in two ways: trilateration or dead-reckoning algorithm.
The flow for trilateration is as follows:

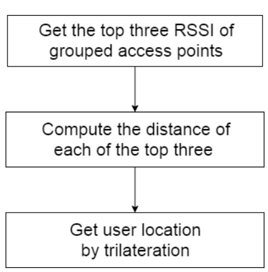

Fig. 8. Trilateration Workflow

If there are at least three scanned access points in the grouped data, then trilateration can be applied. With the use of WifiManager [31], an Android library, the nearby wireless access points was scanned which contains of the necessary information for computation such as the RSSI and the MAC address of each access points. Since there could be sudden changes with the RSSI due to the environment and the reliability of the connection with the network, the scan was done simultaneously ten times per 0.5 second and the RSSI values gathered was filtered and averaged.
The MAC address was utilized in order to get the x, and y values of the said wireless access points, and these x, and y values was used for the computation of the location.
Using the RSSI values, the distance of the user from the said wireless point can be computed. From the equation 2, it can be transposed in order to get the distance [**?**] as shown in equation 6.

$$d = 10^{\frac{p_{tx} - rssi}{10 \times n}} \tag{6}$$

For this study, the path loss exponent chosen was between 3.7-4.5 as it is typical path loss exponent for environment with obstructions [20], [25].
Using the map with the wireless access points, the MAC address of the access points and with the received signal strength index, the location of the user was approximated. Since the location of each wireless access points has been mapped initially and the distance of the user from the wireless access points can be computed by using the RSSI Equation 2 aforementioned, the x, y values of the user can be computed with Equation 7 with system of equations.

$$\begin{aligned} {d_1}^2 &= (x_1 - x)^2 + (y_1 - y)^2 \\ {d_2}^2 &= (x_2 - x)^2 + (y_2 - y)^2 \\ {d_3}^2 &= (x_3 - x)^2 + (y_3 - y)^2 \end{aligned} \tag{7}$$

If trilateration is not possible, the application will then check if dead-reckoning is possible. The flow for dead-reckoning is as follows:

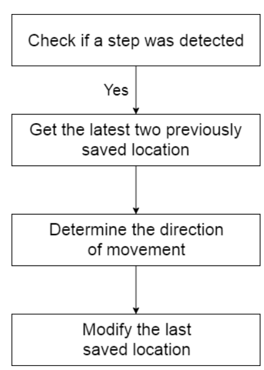

Fig. 9. Dead Reckoning Workflow

The accelerometer of the mobile phone was utilized for this algorithm. A step detector was created and the sensor has a set interval of sensor event changes to listen to before acknowledging a step. If a step was detected, the previous location will be modified with the step length, which was previously set on user settings, and it will be depending on the user's direction which was computed by using the two recent previous locations from the database.

5) Saving data. After the computation of the user's location, it is saved to the local database. After a certain interval, the last data will then be stored to Firebase database.

Meanwhile, for number 2, it is summarized as follows:

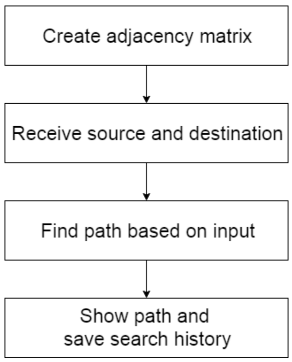

Fig. 10. Navigation Workflow

1) Generate adjacency matrix. This is done at the start of the application which is a pre-requisite for path-finding.
2) Get source and the destination. The map created for localization was represented in ECEF system or the latitude (x) and longitude (y) values. The longitude and latitude determines the location in a given floor. For this step, geocoding is used which is implemented by receiving the input location of the user, the string is transformed to the id to be searched in the database and then, the information about the said room is also retrieved.
3) Find path based on input. A* Search Algorithm with the usage of Euclidean distance heuristic was used for optimal route finding.
   Below is the pseudocode for A* Search Algorithm [32]:

```
fnc AStar(problem){
 openList = {initialState}
 closedList = {}

 while(openList is not empty){
   path h.getLast(); closedList.add(s)
   if(GoalTest(s)) return path

   for a in = openList.removeMinF()
   s = patActions(s):
     x = Result(s,a)
     if(x is not in openList or closedList)
     or (x is in (openList or closedList)
     and x.G < duplicate.G )):
      openList.add(path + x)
    }
}
```

4) Show path and save search history. The path is then showed to the user, which is simply shown by arrows towards the areas to be traversed. Afterwards, the destination is saved to the local database.

3) Admin Application:
The system administrator also has the same capabilities of the normal user, but has additional capabilities such as viewing previously saved location of the users, and handling map information and bug reports.

V. Results and Discussion

A. Indoor Map

The maps were created using Inkscape and is represented in SVG. The location of the access points are represented with a filled square. It is then used in both the user application and admin application.

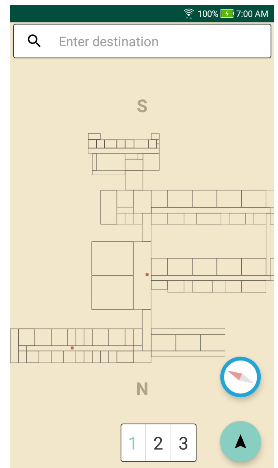

Fig. 11. Indoor Map in User Application

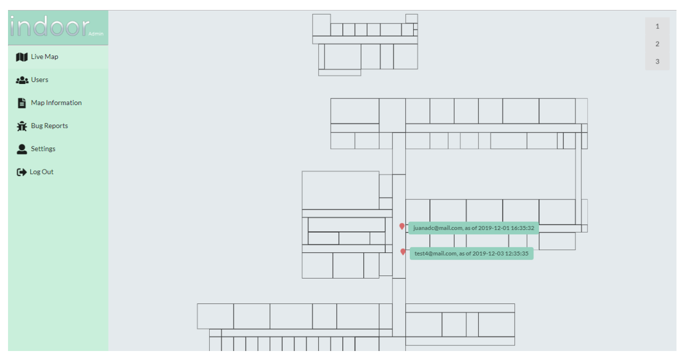

Fig. 12. Indoor Map in Admin Application

B. Getting Location

1) Pre-testing: As seen on the map, there are not a lot of access points in the Physical Sciences building. Hence, there were areas where the application cannot compute for the user location because the scanned access points are less than three.

With that, an area was selected where trilateration is possible. The test area is located on the second floor in the PhySci hallway or the hallway connecting Wing A, Wing B, and Extension.

Name	X	Y
Physci Hallway Start	183	212.69
Physci Hallway Middle	183	194.42
Physci Hallway End	183	145.93

TABLE II
Coordinates of the Test Points

Based on the previous studies, the range for the value of n (or the path loss exponent for the Equation 2) was 3.7-4.5 [20], [25]. In order to get an exact value of n for the test area, the researcher tested the values between the said range every 0.05. Afterwards, the distance of the computed coordinates from the expected coordinates was taken. With the distance, the mean squared error (MSE) of each data set was taken and the value of n that has a data set with the lowest MSE was used.

Value of n	Mean Squared Error	Index
3.70	3153.146	16
3.75	1529.812	1
3.80	2025.455	3
3.85	3133.121	15
3.90	2072.808	4
3.95	2246.217	5
4.00	5171026	17
4.05	2873.901	13
4.10	1640.535	2
4.15	2360.657	6
4.20	2588.684	9
4.25	2619.874	10
4.30	2436.499	7
4.35	2470.804	8
4.40	2697.658	12
4.45	2893.515	14
4.50	2684.477	11

TABLE III
MSE OF THE DATA SET FOR EVERY VALUE OF N

Each row from Table III represents a data set with specific value of n. The row with the lowest MSE is where n = 3.75. Therefore, in this study and in the experiment area, the value of n used in the RSSI formula is 3.75.

2) Testing: Ten tests spread out during the weekdays were done to test the application. Below is the average error for each data set by X and Y values and the overall average error of the data sets.

Index	Ave Error X	Ave Error Y
1	48.24375	1.598553
2	147.3378	2.903612
3	119.7797	2.598757
4	178.4716	1.235174
5	315.8197	2.22221
6	64.70521	2.875819
7	233.3084	2.885941
8	31.78647	2.609612
9	51.57756	1.385244
10	48.22263	2.370384

TABLE IV
AVERAGE ERROR FOR X AND Y IN 10 TRIALS

Overall Ave Error X	Overall Ave Error Y
123.9253	2.268531

Fig. 13. Overall average error of 10 trials

C. User Application

Using the materials and methods discussed, the user application was developed. It has two major features:

1) The application scans and computes for the user location using trilateration and RSSI formula.

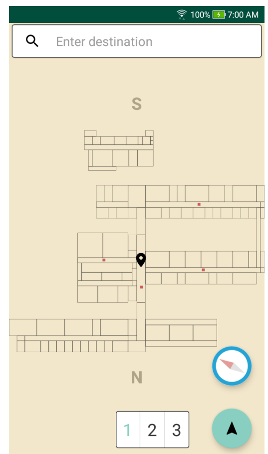

Fig. 14. Home with pin

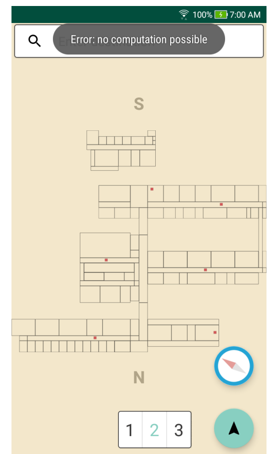

Fig. 15. No computation

2) The application receives input source and destination from the user and shows the optimal path.

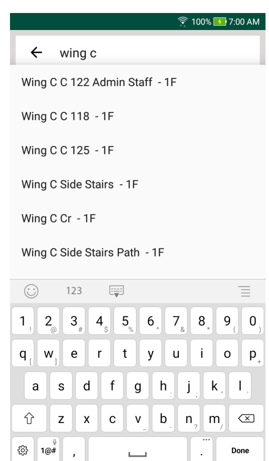

Fig. 16. Entering room

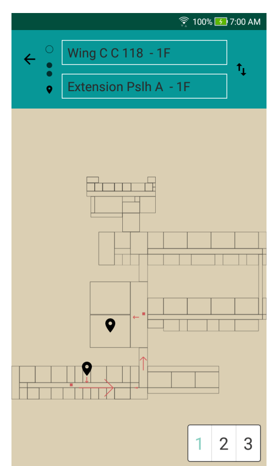

Fig. 17. Showing path

Meanwhile, these are the screenshots of the other features:

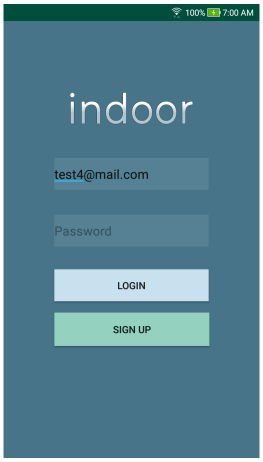

Fig. 18. Login Page

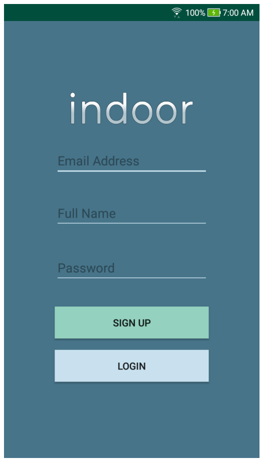

Fig. 19. Register Page

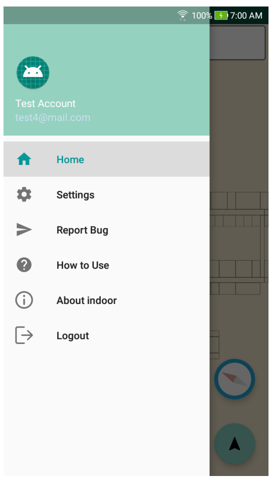

Fig. 20. Navigation bar

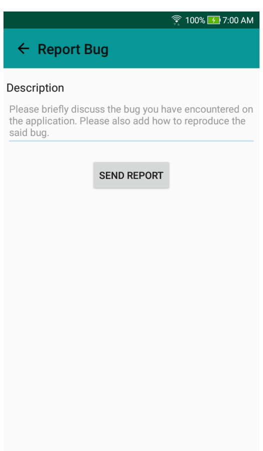

Fig. 21. Report Bug Page

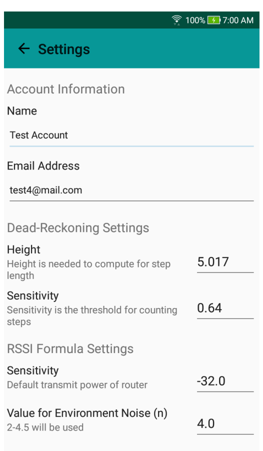

Fig. 22. Settings Page

D. Admin Application

The admin application includes only all of the system administrator capabilities such as the viewing current location of users, handling map information and bugs. Below are the screenshots of the application:

Fig. 23. Login page

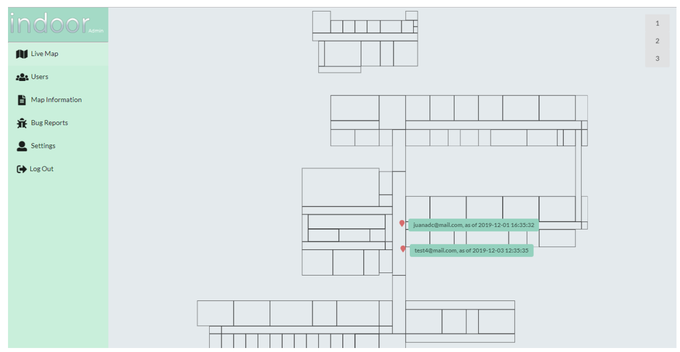

Fig. 24. Live map page

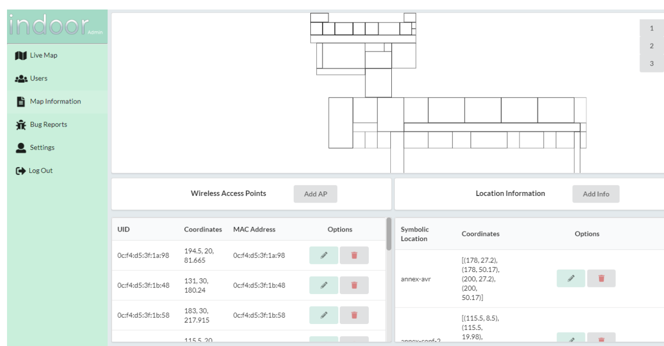

Fig. 25. Map information page

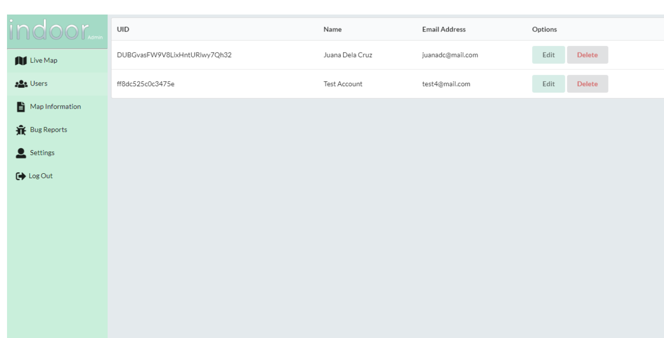

Fig. 26. Users page

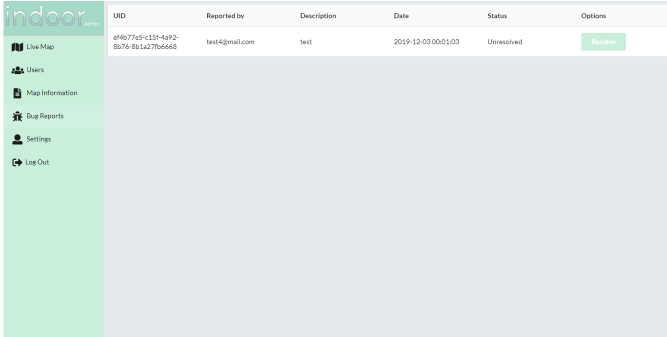

Fig. 27. Bug reports page

VI. Summary and Conclusion

The map containing the relevant information such as the access points and the rooms were successfully created. The user application that applies the methods aforementioned was also successfully implemented in the tested Android phone. The admin application was also successfully implemented based on the specifications. Overall, the study was able to make use of the existing infrastructure of the building.

The said building does not have enough access points to fully make use of the application, so an experimental area had to be chosen. For the localization itself, as seen on Figure 13, the overall average error for X is 123.93% while the average error for Y is 2.27%. In the test area, where the value of n = 3.75, it can be concluded that the indoor application with the usage of RSSI formula fails to accurately estimate the user's location.

Meanwhile, the pathfinding method was successfully implemented. It was able to output which rooms or hallways have to be traversed in order to reach the destination. However, the visualization cannot be optimized due to the limitation of the map representation.

VII. Future Works

To improve the localization, a Bayes filter, like Kalman filter, could be used to improve the handling of the signal's noise. The value of n could also be modified and adaptive, depending on the areas inside the building which could be done by gathering large amounts of data and training a neural network. A newer model of the device can also be used which has better hardware.

The map representation could also be improved by including more points in each rectangle or adding entry points in the rooms which could help in creating a better visualization for path finding. The generation of adjacency matrix could also be sped up by caching and systemic modification once changes in the map are detected.

References

[1] (2017, Aug. 29) What is gnss? [Online]. Available: https://www.gsa.europa.eu/european-gnss/what-gnss

[2] M. Kaluža, K. Beg, and B. Vukelić, "Analysis of an indoor positioning systems," *Zbornik Veleučilišta u Rijeci*, vol. 5, no. 1, pp. 13–32, 2017.

[3] E. Matchar. (2017, Dec. 22) The rise of indoor navigation. [Online]. Available: https://www.smithsonianmag.com/innovation/rise-indoor-navigation-180967632/4Bg6g6G7RuD2jHze.99

[4] M. Lemmens. (2013, Oct. 28) The rise of indoor navigation. [Online]. Available: https://www.gim-international.com/content/article/indoor-positioning-2

[5] D. Dardari, P. Closas, and P. Djuric, "Indoor tracking: Theory, methods, and technologies," *IEEE Transactions on Vehicular Technology*, vol. 64, no. 4, p. 1263–1278, Apr. 2015 2015.

[6] MarketsAndMarkets. Indoor location market worth 40.99 billion usd by 2022. [Online]. Available: https://www.marketsandmarkets.com/PressReleases/indoor-location.asp

[7] G. Jekabsons, V. Kairish, and V. Zuravlyov, "An analysis of wi-fi based indoor positioning accuracy," *Scientific Journal of Riga Technical University*, vol. 47, no. 1, pp. 131–137.

[8] H. Liu, H. Darabi, P. Banerjee, and J. Liu, "Survey of wireless indoor positioning techniques and systems," *IEEE Transactions on Systems, Man and Cybernetics, Part C (Applications and Reviews)*, vol. 37, no. 6, pp. 1067–1080, Nov. 2007.

[9] Locatify. Indoor positioning systems based on ble beacons - basics. [Online]. Available: https://locatify.com/blog/indoor-positioning-systems-ble-beacons/

[10] Y. Wang, "Indoor localization based on visible light communication," Master's thesis, 2017.

[11] Y. Bai, S. Wu, H. Wu, and K. Zhang, "Overview of rfid-based indoor positioning technology," presented at the Proceedings of the Geospatial Science Research_2 Symposium 2012, 2012, pp. 1–10.

[12] D. Vandermeulen, C. Vercauteren, and M. Weyn, "Indoor localization using a magnetic flux density map of a building," presented at the AMBIENT 2013 : The Third International Conference on Ambient Computing, Applications, Services and Technologies Indoor, 2013, pp. 42–49.

[13] B. Li, T. Gallagher, C. Rizos, and A. G. Dempster, "Using geomagnetic field for indoor positioning," *Journal of Applied Geodesy*, pp. 1–10, 2013.

[14] B. Bimal, S. seung Hwang, and J.-Y. Pyun, "An efficient geomagnetic indoor positioning system using smartphones," 2018.

[15] Y. Zhuang, L. Hua, L. Qi, J. Yang, P. Cao, Y. Cao, Y. Wu, J. Thompson, and H. Haas, "A survey of positioning systems using visible led lights," *IEEE Communications Survey Tutorials*, vol. 20, no. 3, pp. 1963–1988, 2018.

[16] Y. Zhuang, Z. Syed, J. Georgy, and N. El-Sheimy, "Autonomous smartphone-based wifi positioning system by using access points localization and crowdsourcing," *Pervasive and Mobile Computing*, vol. 18, pp. 118–136, 2015.

[17] M. Kjærgaard, M. Krarup, A. Stisen, T. Prentrow, H. Blunck, K. Grønbæk, and C. Jensen, "Indoor positioning using wi-fi – how well is the problem understood?" presented in 2013 International Conference on Indoor Positioning and Indoor Navigation, 2013, pp. 1–4.

[18] C. Chen, Y. Han, Y. Chen, and K. J. R. Liu, "Indoor gps with centimeter accuracy using wifi," presented in 2016 Asia-Pacific Signal and Information Processing Association Annual Summit and Conference, 2016.

[19] C. Chen, Y. Chen, Y. Han, H.-Q. Lai, and K. J. R. Liu, "Achieving centimeter accuracy indoor localization on wifi platforms: A frequency hopping approach," *IEEE Internet of Things Journal*, vol. 4, no. 1, pp. 111–121, Feb. 2017.

[20] C. S. Inc., "Location tracking approaches," in *Wi-Fi Location-Based Services 4.1 Design Guide*, 2008, ch. 2.

[21] M. Zhang, Y. Wen, J. Chen, X. Yang, R. Gao, and H. Zhao, "Pedestrian dead-reckoning indoor localization based on os-elm," *IEEE Access*, vol. 6, pp. 6116–6129, 2018.

[22] H. Bao and W. Wong, "A novel map-based dead-reckoning algorithm for indoor localization," *Journal of Sensor and Actuator Networks*, pp. 44–63.

[23] C. Correia, "Andreck: Positioning estimation using pedestrian dead reckoning on smartphones," M. Communication Networks Engineering thesis, Técnico Lisboa, Portugal, Nov. 2013.

[24] Y. Lai, C. Chang, C. Tsai, S. Huang, and K. Chiang, "A knowledge-based step length estimation method based on fuzzy logic and multi-sensor fusion algorithms for a pedestrian dead reckoning system," *International Journal of Geo-Information*, vol. 5, 2016.

[25] (2017, May 29) Wifi trilateration with three or more points. [Online]. Available: https://appelsiini.net/2017/trilateration-with-n-points/

[26] Y. Jin, H. Toh, W. Soh, and W. Wong, *A Robust Dead-Reckoning Pedestrian Tracking System with Low Cost Sensors*, vol. 5, 2016.

[27] Google. Get started — geocoding api — google developers. [Online]. Available: https://developers.google.com/maps/documentation/geocoding/start

[28] A. Murphy and D. C. M. et al. Mean squared error. [Online]. Available: https://https://radiopaedia.org/articles/mean-squared-error

[29] What are mean squared error and root mean squared error? [Online]. Available: https://https://www.vernier.com/til/1014
[30] "R500." [Online]. Available: https://webresources.ruckuswireless.com/pdf/datasheets/ds-ruckus-r500.pdf
[31] Wifimanager. [Online]. Available: https://developer.android.com/reference/android/net/wifi/WifiManager
[32] K. Pelaez, "Lecture slides in cmsc 170, problem solving agents," Feb. 2018.