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Bluetooth Based Indoor Positioning System

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***Abstract*—** As times have passed, the world has always chosen to get work done in faster and faster ways. As a result, many contributions to the society have been provided by people all around the globe. One such contribution is the development of navigation systems to make people find their destinations more quickly and mainly accurately. Bluetooth based navigation systems are developing at a faster rate and with the appearance of the open Android operating system, wireless technologies are being developed faster than ever. Many indoor positioning techniques are also being developed using Bluetooth but the problem that arises is regarding accuracy. Most of the techniques fail to provide satisfactory accurate results and hence the indoor location services are lacking behind. One more problem is the complicated interfaces and display technique. Also, the world is moving into the era of smartphones. Everyone wants everything on their smartphones, also the location services. In this project, we have proposed to improve the accuracy of the location services, designed on Android platform to be used in smartphones with a less complicated and simple as well as useful interface as compared to existing systems. The project is presented by the use of Bluetooth Low Energy beacons and an android smartphone in order to navigate a location particularly in an indoor area by the help of RSSI values. RSSI values are the coordinates generated by the beacons to display a location point and with the help of some formulae and calculations, we can find the most accurate location with at least a range of 70%.

Keywords—Bluetooth Low Energy beacons, localization, RSSI.

I. INTRODUCTION

Due to the ease of deployment, low cost, and potential applications in the smart building, security, and healthcare, indoor positioning system (IPS) gets significant attention in these recent years. Mobile positioning has become increasingly interesting system most notably for context-aware application and emergency services, which works in ad hoc manner. The Global positioning system (GPS) has been the mainstream technology for location and tracking for outdoor environment but cannot be used indoor. GPS requires a direct view to several satellites, resulting in limited performance for indoor environments. GPS signal in an indoor environment is too faint to provide sufficient accuracy. Development of non-GPS based solutions are of great interest for the IPS applications.

A number of commercial systems and research prototypes are developed with different kinds of localization methods. These methods generally use infrared (IR), ultrasound, or radio frequency (RF) system. Bluetooth low energy (BLE) is also very useful in IPS, which is designed for a short-range wireless transmission while maintaining low energy consumption, small size, and low cost.

However, there are many techniques used in the domain of BLE beacons for the indoor positioning system. Fingerprinting, trilateration, and triangulation are all well-established methods with BLE beacons. However, these methods are either tedious or require precise distance estimation through the proper analysis of beacon signals.

Bluetooth Low Energy (BLE) is a low-power wireless technology developed by the Bluetooth Special Interest

Group (SIG) and a distinctive feature of the Bluetooth 4.0 specification. BLE is based on IEEE 802.15.1. BLE devices are represented in two roles: central and peripheral devices. The main roles of BLE Central device are scanning and connecting to the surrounding BLE peripherals. In turn, peripheral device is responsible for advertising specific data and accepting connection request comes from the central. The BLE device may be central and peripheral at the same time. BLE offers low energy consumption, low hardware cost and small size.

In this project we will be developing an android Bluetooth based indoor navigation system with the use of Bluetooth Low Energy beacons (BLE) using the trilateration method based on the RSSI values obtained and then calculating them to produce a point of presence directly on the user's smartphone with a simple and less complicated type of interface with maximum accuracy.

II. TRILATERATION

Trilateration is a surveying method used to determine the horizontal positions. In addition to other methods like triangulation, intersection, resection and satellite positioning. Trilateration is a method that works with distances and is the major working principle followed in Global Positioning System (GPS). Trilateration method measures the RSSI values, the property of an RF signal, then translates these values into distance and solves for the position of the device using geometry.

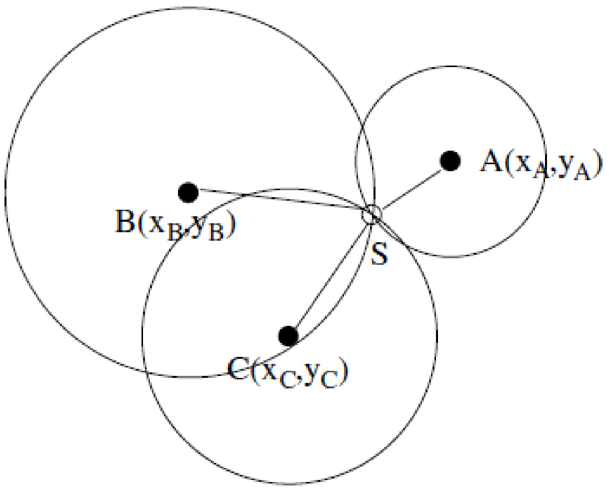

Fig. 1: Trilateration method

A. Trilateration and Triangulation

Trilateration is a method where distance is measured and not angles whereas triangulation is a method where angles are measured and not distance. There is a huge difference in these two techniques and multiple works have been done on both the methods in order to achieve more accurate and desirable results in indoor positioning systems.

In our project, we have proposed to improve the accuracy by using the trilateration method. But it is important to know the difference between triangulation and trilateration.
Difference between triangulation and trilateration:

Triangulation	Trilateration
Measures angles and not distance.	Measures distance and not angles.
A base line whose value is known is taken as a reference for proceeding the measurement.	The azimuth of a line is the known value and it is taken as the reference to proceed the measurement.

Table1: Difference between Triangulation and Trilateration

B. Trilateration and Fingerprinting

Fingerprinting is the most popular method of localization because of its high accuracy compared to other methods. It does not require line-of-sight measurements of APs, has low complexity, and gains high applicability in the complex indoor environment. Fingerprinting-based localization usually consists of two main phases: offline (training) and online (test).

The offline phase of fingerprinting is designed for learning the RSSI at each reference point. At this stage, we collect RSSIs from all beacons. RSSIs in four directions, at each measurement location are collected. These collected RSSIs are stored in a database along with their location coordinates, which are called reference points (RPs).

In the online phase, RSSIs from beacons are measured and compared with the stored ones in the database. Then, the location of the tag device is estimated using the fingerprinting procedure.

In the arena of indoor location positioning techniques, fingerprinting has been a prime choice for researchers due to its good estimation. However, the inevitable drawback of this method is the requirement of a tedious and time-consuming offline phase. Also, though WCL seems easy and flexible to implement, it has a high localization error.
Thus, the best suitable method according to the research in our project is the trilateration method.

III. LITERATURE REVIEW

A number of researches and experiments have been done in recent years in the positioning field. Few of them are done in indoor based positioning system specifically. Various researchers have used different techniques of calculating the exact location, but the result varies in the accuracy part.
Bluetooth indoor positioning by using machine learning algorithms where fingerprinting technique is used (Pranesh Sthapit1, Hui-Seon Gang2 and Jae-Young Pyun3). Indoor Positioning using BLE and then filtering the coordinates using the Kalman filter for better accuracy (Eslam Essa, Bassem A. Abdullah and Ayman Wahba). Arduino based Indoor Positioning by visible light communication and ultrasound communication where LED shields are connected to the Arduino Uno in order to get global position relevant to the position of LED lamps inside the area (Lih Chieh Png, Liangquan Chen, Song Liu, and Wei Kuan Peh).
Indoor Positioning using BLE beacons with fingerprinting technique particularly Naïve Bayes and Random Forest techniques with an accuracy of over 91% (Fernando Campana, Adriano Pinargote, Federico Dom ˜ ́ınguez and Enrique Pelaez ́ Centro de Tecnolog ́ıas de Informacion). An Indoor and Outdoor Seamless Positioning System Based on Android Platform. In this paper, build an Android application which achieved the aim of seamless positioning between the inside and the outside. The system contains four parts: outdoor positioning, which uses GPS and Baidu Map; indoor

positioning, which adopts Wi-Fi fingerprint positioning; contextual detection, including indoor and outdoor detection and floor detection, which takes advantage of multiple sensors integrated on Android (Minglei Jia1, Yanqin Yang 1, Lei Kuang1, Wenchao Xu).
Low Power Wearable Device with GPS And Indoor Positioning System. Human movement tracking system is used. It estimates the location of the human by calculating the distance and direction of the person moving. When the user enters an indoor environment. RFID reader will be triggered if GPS fails to get signal from satellite and Arduino will start human movement tracking system (Miew-Huang Ngui ,Wai-Kong Lee**).**

IV. System Design

A. *Methodology*

In this paper, we propose a solution composed by a trilateration technique, an android app server, a smartphone and a Bluetooth Low Energy (BLE) 4.0 beacon infrastructure. The beacon infrastructure was designed to obtain a good distribution of beacons across the building. The App's purpose is to read the data packets sent by the beacons over a period of time and send the information of the beacons found to the server for further processing. The server was responsible for saving and processing the data or packets, so they can be used in an algorithm to predict a location.

The beacons are used to estimate the distance which are sent by them in the form of packets and the packets are then decoded in the concept called Received Signal Strength Indicator (RSSI). It measures the signal strength when the transmitter transmits the signals to the receiver.

The architecture was composed of 3 BLE beacons and multiple smartphones. Each beacon was placed 5 meters apart form each other. All the beacons were placed at a height of 2 meters from the floor. All the 3 beacons were placed in a grid space layout. Each beacon produced some RSSI values in the smartphone as soon as the app and the beacon device were switched on. The values were recorded in the phone. The phone was held at a height of 1.2 meters from the floor as it is a usual height of a user standing when using the phone. Here the transmit power played an important role. The transmit power of the beacon was set to -12dBm. As the transmit power varied, the patterns of the RSSI values started to take changes which clearly states that higher transmit power leads to the increase of higher RSSI values. We started to observe the readings close to the beacon, roughly 1 meter apart. The beacon was always in the line-of-sight of the smartphone. Then we extended the distance between the beacon and the phone to 5 meters apart.

Continuing this process, we recorded the RSSI values of all the 3 beacons starting with 1 meter apart to maximum 5 meters apart. All the values were recorded and now it was time to conduct a regression analysis by using the propagation model. A propagation model is basically an equation which usually describes the relation between the RSSI values and the distance. Basically, it converts the values obtained from the RSSI of the beacons to the distance giving a perfect mathematical value helping to be more accurate for calculations.

In order to calculate the distance between a smartphone and a beacon, an equation needs to be expressed and solved. This equation is a part of the propagation model and the equation is as follows:

$$D = C1 * RSSI\ Txpower\ C2 + C3 \ldots..[1]$$

Where, RSSI is the Received Signal Strength Indicator measured by the smartphone while reading the signals transmitted by the BLE beacons. Txpower is basically the value of the RSSI at a distance of 1 meter. C1, C2, C3 are the constants which are fully dependent on the Bluetooth Chip of the smartphones and the antenna and they can be easily calculated for a particular device.

A Bluetooth Low Energy (BLE) beacon carries information of it such as:

1) The beacon ID which is unique for every device.
2) The name of the beacon which can be optional.
3) Calibrated RSSI value of its own at 1 meter.
4) Calibrate RSSI value at 0 meter (Eddystone).

B. *Working of Software*

The software used in our project is an android app which holds an operating system namely Android 4.0 or later. The app has been designed on the Android Studio platform or software which is built on JetBrains IntelliJ idea's software. This software is a officially integrated platform or environment for google android operating system designed specifically fir android development. The programming language used in the app for coding is the Java language which is one of the most popular programming language in the world.

The software which is an Android application contains of 4 layers. The 4 layers are described as follows:

- The first layer of the software consists of two domains namely the RSSI domain and the orientation domain. Both the domains or services start performing as soon as the app is opened and keep on working till the app has been closed or terminated. The orientation service reports the orientation of the smartphone to the server whereas the RSSI domain listens to all the Bluetooth signals released by the BLE beacons and gathers the RSSI values of those signals and the MAC address of the signals and reports them to the server.
- Each sample or RSSI values recorded or reported contain some or many null values and abnormal stuff such as spikes or hard codes. The second layer of the software is basically a pre-processing layer which samples the RSSI values reported at a duration of every 9 seconds. After sampling, the inappropriate stuff according to the server like abnormal spikes are discarded from the software. The rest of the values are recorded and then forwarded to the third layer.
- In this project, we have implemented trilateration method to know a location. In trilateration method, a position or a location is calculated on the basis of 3 values recorded from 3 different beacons all reported in the smartphone. Here comes the third layer of the software. This the main and the core layer of the software which is the position algorithm. All the calculations are done in this layer using the formulas and the position is determined in this layer.
- The fourth and the last layer carries out the display work. This layer functions to display the calculated

position, the end result on the map with respect to the four quadrants.

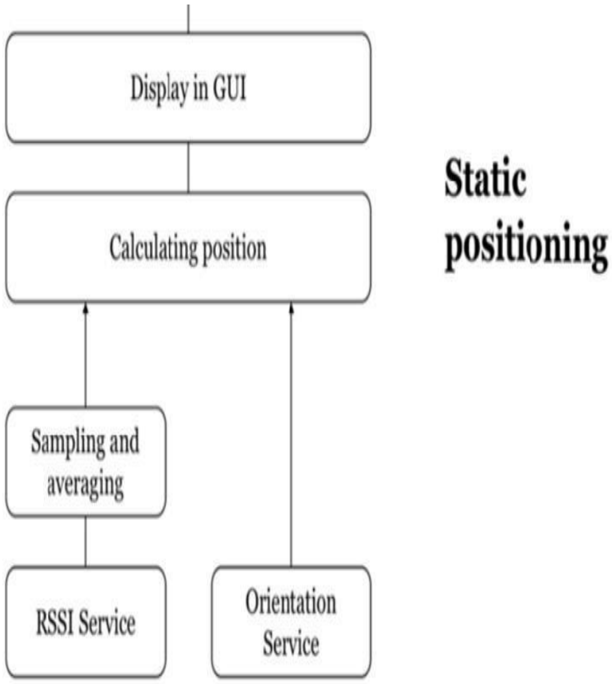

Fig. 2: Architecture of the Software

C. *Distance Calculation*

After collecting the RSSI values from the different positions of all the 3 beacons, the values were stored in the smartphone and now they had to be calculated in the form of distance. The values that got recorded were:

Distance(m)	0.25	0.5	1	2	3	4	5
RSSI(dB)	-65	-69	-59	-52	-72	-83	-86

Fig. 3: RSSI Values at Different Distances from Beacons

After collecting all the values, we converted the recorded RSSI values into their calibrated RSSI values at 1 meter each. The reason behind this is that the IBeacon mentions that for a beacon transmitting at -12 dBm, the RSSI at 1m should be -77 dB.

After performing this part, we realized that using 3 BLE beacons for measuring the position results in better performance. The reason behind this is the RSSI do not always reflect the distance correctly due to reflection and multi-path effect, hence using less beacons avoids introducing the erroneous information to the system. We concluded that using pseudo intersections and 3 beacons greatly improves the accuracy of the position or coordinates and hence 3 beacons is the ideal number for this.

After this, we carried on to calculate the regression analysis to discover the exact 2 coordinates in order to find the distance. Analysis was done on the basis of the values of fig. 3. The graph obtained after doing the regression analysis was a curve fit to the measurements. The distance here was measured in meters and the RSSI values were measured in dB. The graph obtained after performing regression analysis is shown below:

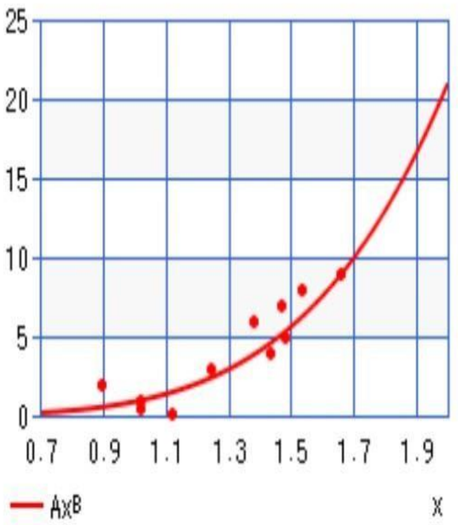

Fig. 4: The regression analysis (on x-axis: Ratio of RSSI values, on y-axis: Distance)

The regression analysis gave a best fit when a = 0.882909233, b = 4.57459326

According to the equation [1], the distance is measured as follows:

$$D = 0.89976 * \text{RSSI Txpower } 7.7095 + 0.111$$

Note that D here is the distance of the smartphone to the BLE beacon used in the trilateration calculations.

D. *Position Calculation*

In trilateration method, three imaginary circles are drawn considering the distance of each beacon as its radius. The circles are assumed as the coverage area of the beacons. Now according to the circles drawn with respect to radius, wherever the three circles of the three beacons intersect at a point, that point is considered as the position of the user and hence the location is found out. If there is anything wrong about the distance values or some error in the coordinates, then the three circles obtained by the radius of the three beacons will not intersect anywhere and hence we will not get the desired output which is ultimately the position of the user. By this, we can determine that the output has some error and hence needs to be corrected.

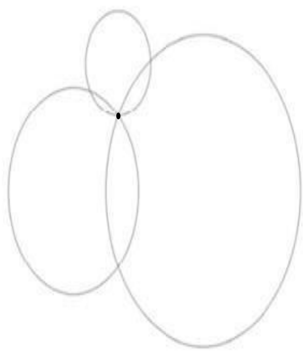

Fig. 5: Intersection Point of the 3 circles

- *E. Tools Used (Hardware & Software) .*

In hardware part, we had used the Bluetooth Low Energy (BLE) beacons of version 4.0 that get connected to nearby devices easily and broadcast their identifier easily to portable electronic devices. These beacons are used for short range communication purposes and are low in cost, easy to carry and not much complex design devices. The other device that was used was a smartphone to display the position of the user.

In software part, we had develpoed an application by using the popular software which is named as the Android Studio and the whole programming part of the app was done in Java programming language.

V. RESULT & DISCUSSION

The Trilateration method proved to be a much simpler and less complex technique as compared to triangulation and the fingerprinting techniques. Also the results obtained were of much more accuracy than the other methods. Some of the techniques like the fingerprinting technique using machine learning algorithms may prove to give much better accurate results but then the complexities too increase in such methods leading to a lot of technical errors hence yielding non accurate results for the most of times. Triangulation method can also be used as a better technique but as it measures angles and not distances, calculation becomes much complex and hence error rate increases as well. The best method proposed by us is the trilateration method with less complexities and better results. The results after performing the trilateration method are shown in the table below:

Position	1	2	3	4	5
Correct estimates	72%	60%	75%	69%	64%

Fig. 6: Accuracy at Different Positions

In the application, we had to perform and display the positions in the quadrant form, by displaying points in each quadrant. The reason for this was the room used by us had very low existing sensitivity, but it could had been more accurate if we had used better filtering techniques like the Kalman filter.

Now as we start the application in the smartphone, it gets started with the receiving of the coordinates and the software works on to display the results. As the user is moving continuously and not steady all the time, the difference in the measurements also occur. So the application gets updated after every 10 seconds so as to deflect errors in the measurements and transfer the right coordinates according to the position of the user. The results displayed in the smartphone after various movements and coordinates received are shown below:

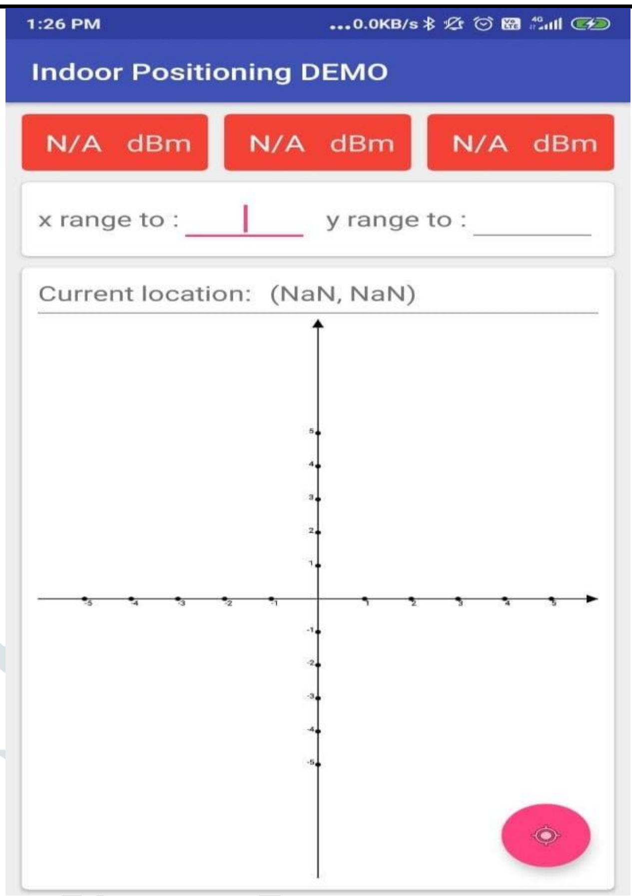

Fig. 7: Application Interface

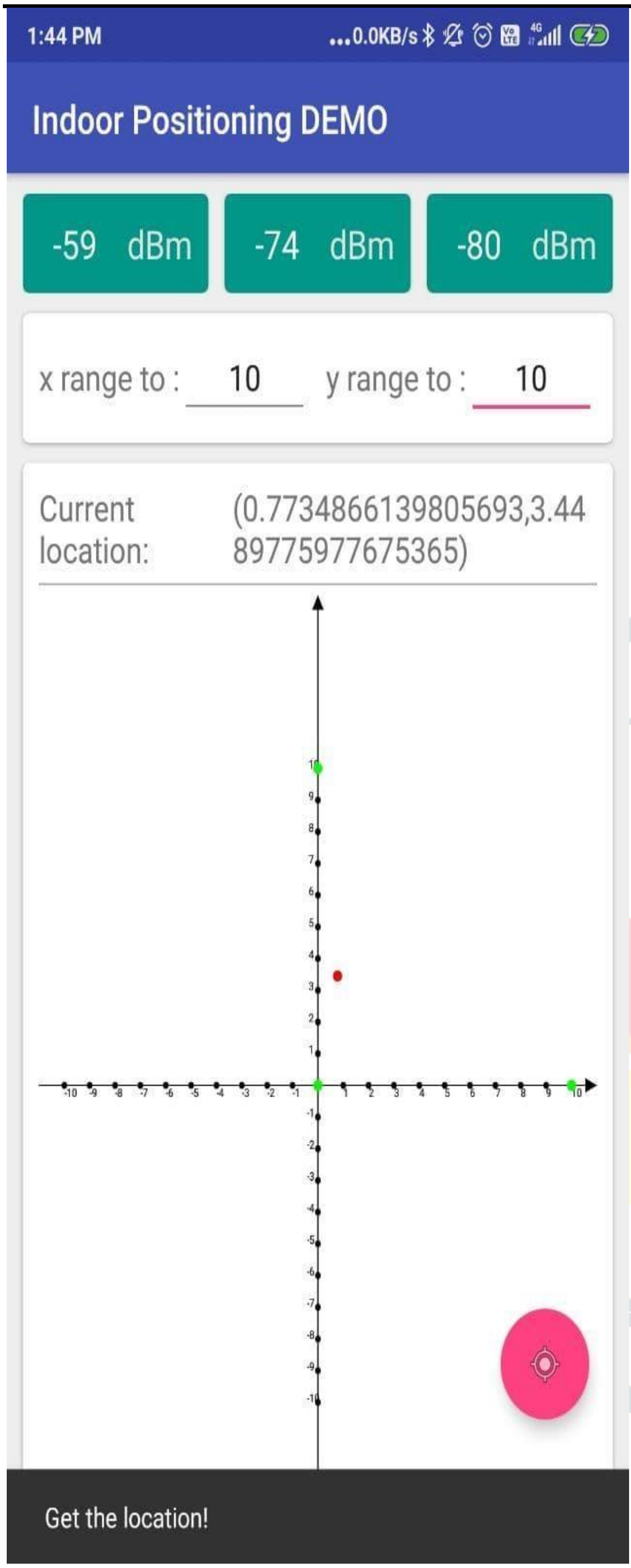

Fig. 8: Position displayed in 1st quadrant

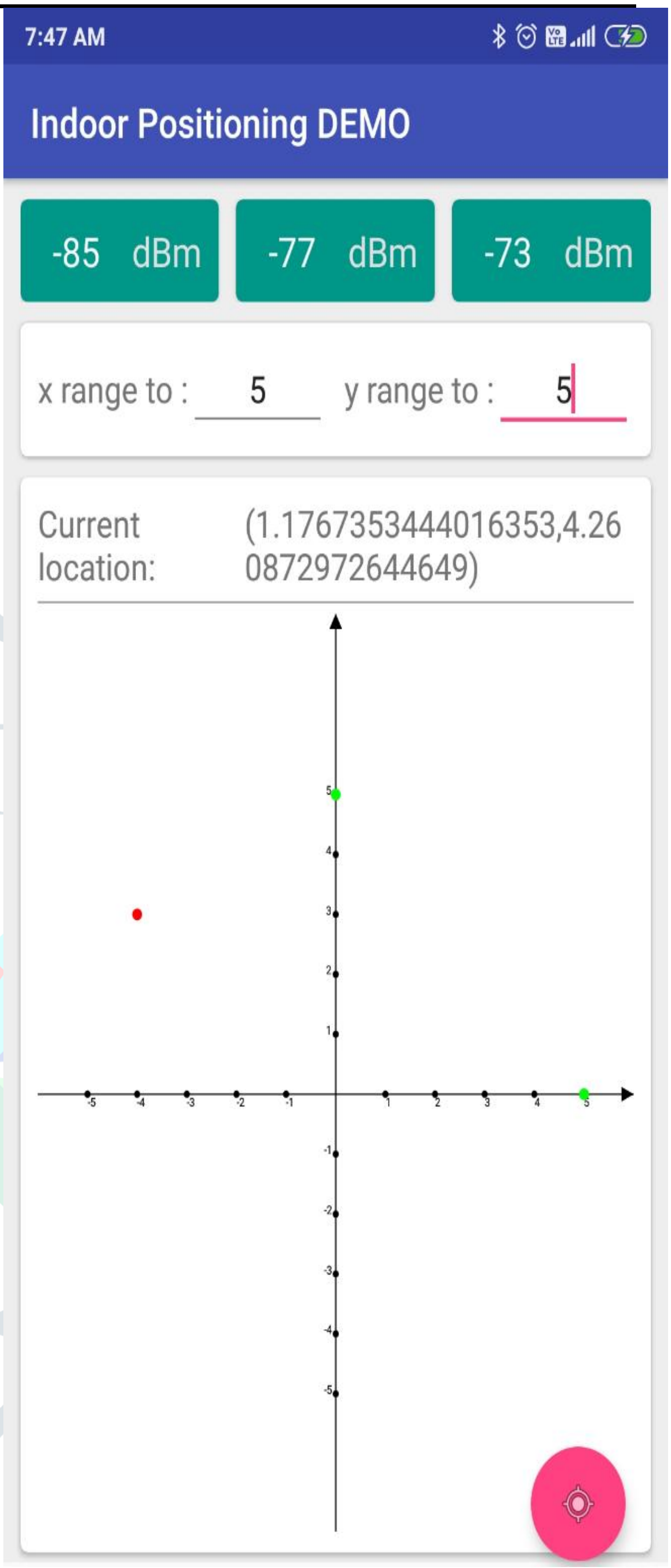

Fig. 9: Position displayed in 2nd quadrant

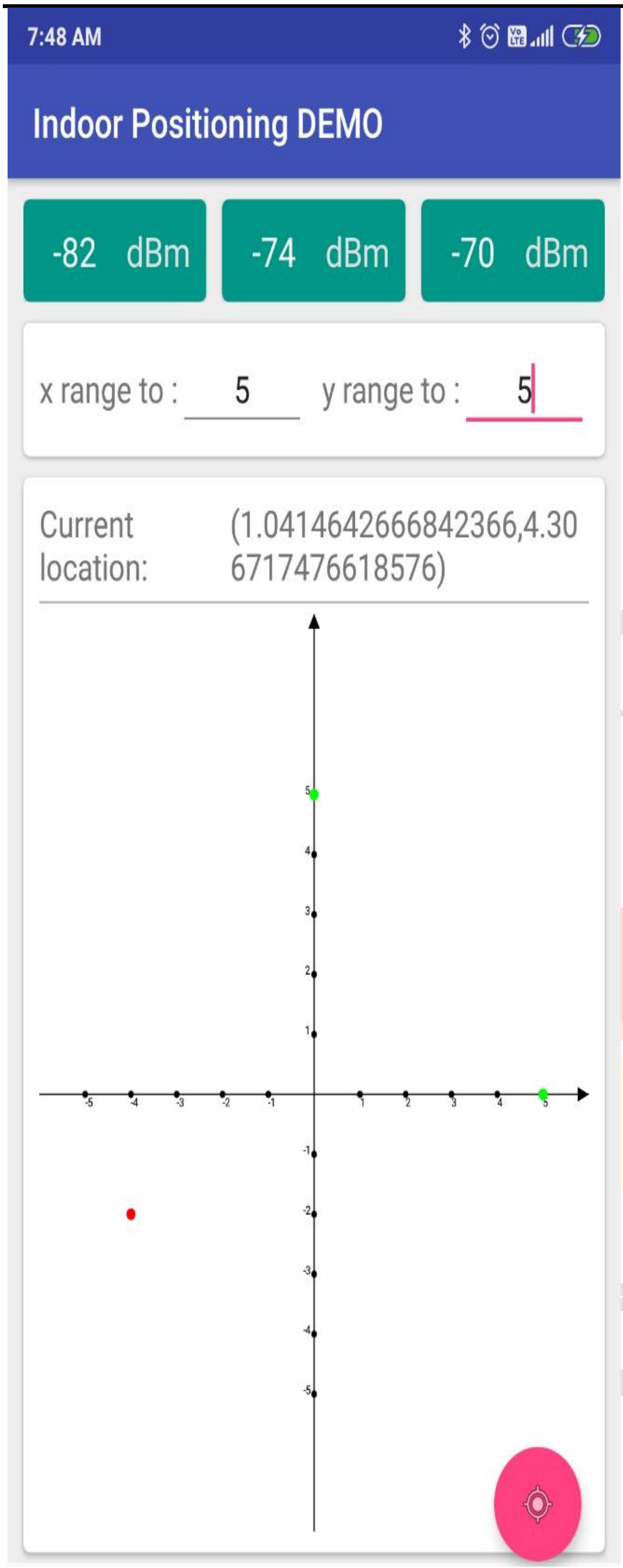

Fig. 10: Position displayed in 3rd quadrant

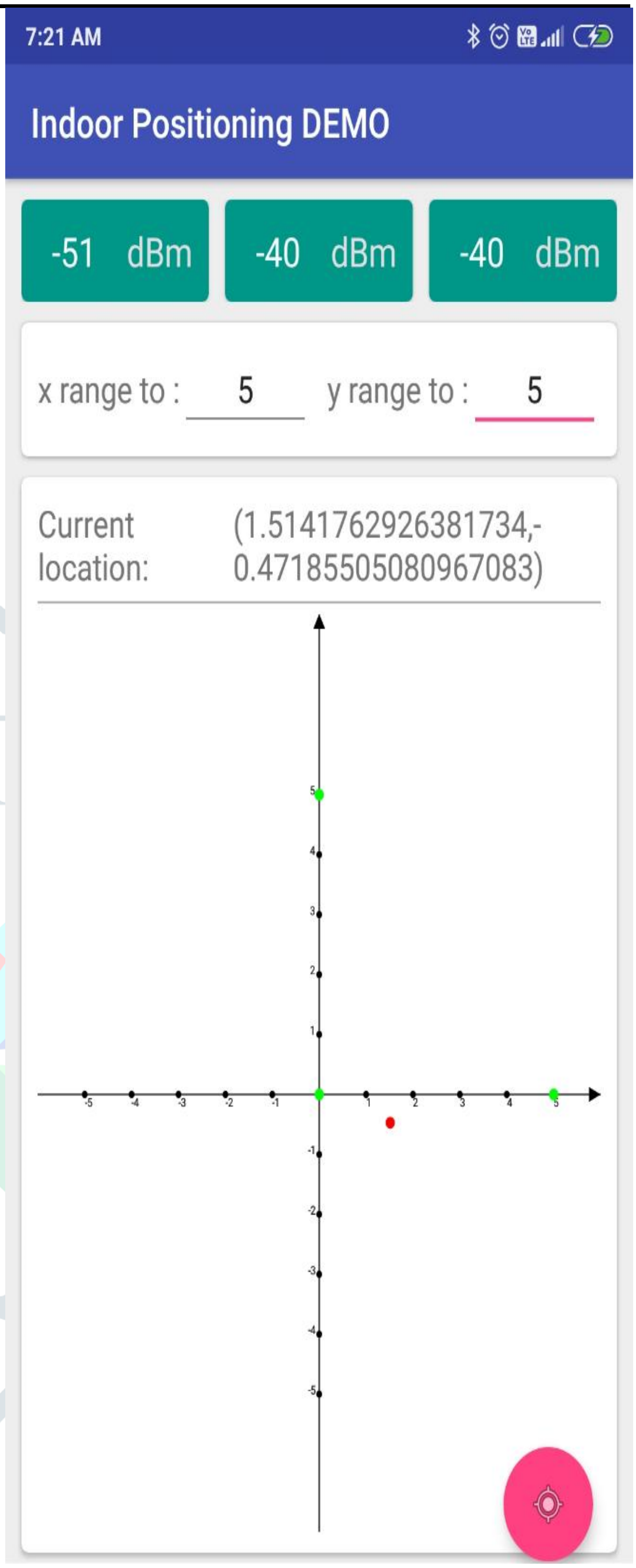

Fig. 11: Position displayed in 4th quadrant

VI. CONCLUSION & FUTURE SCOPE

In this project, we have successfully managed to find a indoor positioning of a user with the help of the trilateration technique with a great amount of accuracy. We have presented a cost effective BLE indoor positioning system to detect the locations of passings- by with a much greater accurate value in office or laboratory environments with very few false detections in real time. The calibration process is time-efficient and straightforward, and scales easily with greater area, compared to fingerprinting-based methods. The Indoor Positioning System is meant to be used in various fields, especially in small to mid-sized manually operated warehouses. We conclude that the localization accuracy depends mainly on the type of hardware used, the position of the transmitter and receiver, and the success of the calibration phase.

The researchers right now are doing extremely well with the GPS technology with most of the applications using the global positioning system. It definitely has made a huge achievement for people to find themselves and others or to reach to their destinations quickly with the right route. But that much development has not taken place in the indoor positioning sector. This sector is a gold mine and if dug deep, it could give the world a more greater benefit and ease. Many researchers are still studying and working on indoor positioning system to provide a better, much efficient and time consuming as well as simple location service for the indoors. With more advanced technology and enhanced machinery, indoor location sector will have a remarkable accuracy rate and will definitely compete with the best location services like the GPS.

Several new studies should be performed to find the best combinations of BLE beacons and receivers, which are smaller, more energy-efficient and especially economical for large IPS instalments, although the system is intended primarily for smaller to medium sized manually operated warehouses. Additionally, the effect of different placements should be inspected, along with the influence of walking speed. In this setting, the current configuration can become quite expensive for larger areas or multiple rooms, making such a project financially unfeasible for larger warehouses. We also propose that researchers explore the option of beacons and Raspberry Pi stations being reversed—the beacons should be carried around and the Raspberry Pis should be placed on fixed positions. That way battery power requirements could be reduced further, as the Raspberry Pis could be powered via electrical outlets. If possible, BLE beacons that only use single channel for data transmission should be used, to reduce the RSSI information variation and packet loss further.

A. Future Scope.

Finally for the years to come in the near future, outdoor positioning systems will merge with IPS in a seamless way to locate a person with a smartphone anywhere. This means that while current IPS systems involve specialized equipment and applications, future IPS systems will be part of the smartphone operating system and leverage its sensors so any location-sensitive smartphone application will use indoor or outdoor location services as they are available. Though privacy has been a concern since the very beginning of the development of IPS systems, in the future, this will become one of the main considerations for the adoption or choice of specific IPS systems.

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