Effect of Enhanced Trilateration Algorithm on Positioning Accuracy

Mr. Shivashankara* and Dr. H M Kalpana **
*Dept. of E&IE, SIT, Tumakuru, India
shivu.1si15lvs12@gmail.com
**Dept. of E&IE, SIT, Tumakuru, India
hmkalpanaravi@gmail.com

Abstract: Trilateration is one of the most used method in the place position calculation with help of distance calculated using various methods like Bluetooth Low Energy (BLE), Wireless fidelity (Wi-Fi), ultrasonic and etc. As this method is a viable solution because of its less hardware requirement. But in the basic trilateration, accuracy is not so much targeted since it assumes that distances given to algorithm for the calculation of position are accurate. A small error leads to large variance in the position estimation. So, the proposed algorithm is enhanced such way that it estimates position with less errors even though estimated distances are not so accurate.

Keywords: Trilateration; BLE; Position estimation; Positioning accuracy.

Introduction

Now a day's services or applications based on the particular location is so much important with the highest accuracy. There are lot of methods and processes used for getting accuracy in finding the location of a moving object. As in the outdoors Global Positioning System (GPS) [1] [2] is the best solution for locating an object. So, there is a need to provide accuracy in the indoors for many locations based services. For indoor positioning [3] there are lot of technologies and methods to locate person or an object. Technologies like Wi-Fi (Wireless Fidelity) [4], Zig Bee [5], ultrasound and BLE has started showing their advantages in the indoor positioning. As BLE [6] is the less cost, viable and easily deployable solution among all the available services. Since its power requirement very less compared to other technologies, BLE is the most used technology as solution for indoor localization.

Distance calculation is the most important step in the positioning system, which intern depends upon the Received Signal Strength Indication (RSSI) [7] value. RSSI is another concept which depends upon lot of effects or factors. Since positioning has to be done in indoors, direct usage of RSSI for calculation of distance in the indoors leads to more error in the calculated distance. So, there is need for stabilization or filtering of the RSSI to get accurate distance.

Many techniques like triangulation and trilateration are there for position estimation. Where triangulation uses angle of arrival (AoA) [8] to find out the position of an object with respect to two wireless objects with known position. Requirement for triangulation is directional antenna which introduces and increases hardware complexity for both transmitter (BLE beacons) and receiver (BLE device with unknown position). So, simple, less cost and better accurate solution can be obtained using the technique called trilateration. Trilateration [9] mainly reduces the hardware complexity of the devices since it calculates distance using RSSI values and finds out the position using 3 nearest beacons.

Basic Trilateration

Introduction to basic trilateration

Trilateration is the concept used in positioning system for finding the location of an object using the distances from the fixed-point advertiser (i.e. BLE Beacon). In 2-dimensional plane to calculate X, Y values of an object, distance from at least 3 beacons is required. For 3D, it requires distance from 4 fixed points or beacons. Trilateration uses minimum distances from the 3 nearest beacons to calculate the single intersection point of those three circles. Co-ordinates of intersection point itself is the co-ordinates of the moving object, like this unknown position of an object is calculated.

As shown in the Fig. 1 trilateration finds the intersection point where all the three circles meet. Where B1, B2 and B3 are the BLE beacons and the position of BLE device or object need to be calculated. Circles are drawn using the distances between the Beacons and BLE device as the radius and co-ordinates of the beacons as the center points. The point where all three circles meet is considered to be the point where the BLE Device is exists (i.e. co-ordinates of the intersection point are the co-ordinates of the BLE Device). In the figure shows that c is the point of location or position of a BLE object or device.

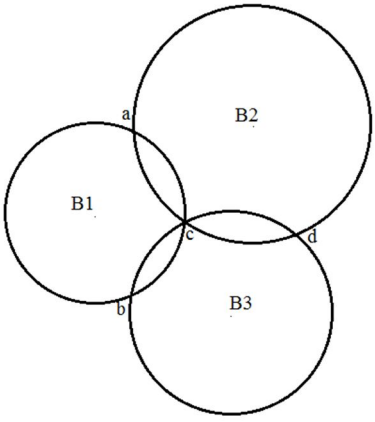

Figure.1. Basic Trilateration

If the basic algorithm of Trilateration used to find out the position of a BLE device, distance from at least three beacons (i.e. B1, B2 and B3) are required. Since Basic algorithm is very simple which find out the perfect point of intersection using set of basic equations for two-dimensional positioning.

$$(x - x_1)^2 + (y - y_1)^2 = r_1^2 \quad (1)$$
$$(x - x_2)^2 + (y - y_2)^2 = r_2^2 \quad (2)$$
$$(x - x_3)^2 + (y - y_3)^2 = r_3^2 \quad (3)$$

According to above equations (1), (2) and (3) (x1, y2), (x2, y2) and (x3, y3) are the co-ordinates of the B1, B2 and B3 respectively. Distances r1, r2 and r3 are the radius of the respective circles B1, B2 and B3. By solving above equations for all the co-ordinate and radius values of Beacons, co-ordinates of BLE device (x, y) can be calculated. The calculated co-ordinate is the only intersection point of all the three circles as shown in Fig.1.

Challenges in Basic Trilateration

Fig. 1 shown above is an ideal case of trilateration. Since no technology is there to find out the exact distance between the two wireless objects. So, errors in the distance are quite common, if errors are there in the distance then there is no perfect intersection point where all three circles meet. If there is no point of intersection where all 3 circles meet, then basic trilateration algorithm fails or falls in ambiguity to find out the exact location or position of the Device. This is the common case where Basic trilateration algorithm is failed to provide its accurate positioning.

As the RSSI is much variant in the indoors which definitely introduces the errors in the distance calculated. These errors in the distance gives 6 intersection points between the circles instead of 4 in Trilateration. It will not give an intersection point where all three circles meet, which leads to more inaccurate positioning of the BLE Device.

As showed by the Fig. 2, it is the one of the case of Trilateration where error in the distance will causes to create more than 4 intersections. As shown a, b and c are the intersection points, appeared because of the error in the calculated distance. In this type of trilateration case (i.e. practical case) use of basic trilateration algorithm will causes the inclusion more error in the position accuracy since the algorithm itself is inputted by erroneous distance. To avoid these miscellaneous errors occurred during the calculation distance from the RSSI, Proposed algorithm enhanced such way that it removes almost marginal errors during the estimation of position.

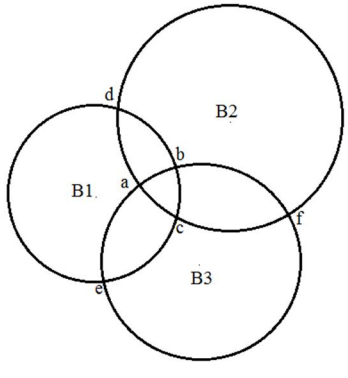

Figure.2. Practical Case of Trilateration

Proposed Trilateration Algorithm

So, the proposed trilateration algorithm is modified such way that instead of calculating directly the intersection point between the three circles, algorithm calculates intersection between two circles in all combination (for above case as in Fig. 2 intersection points are calculated).

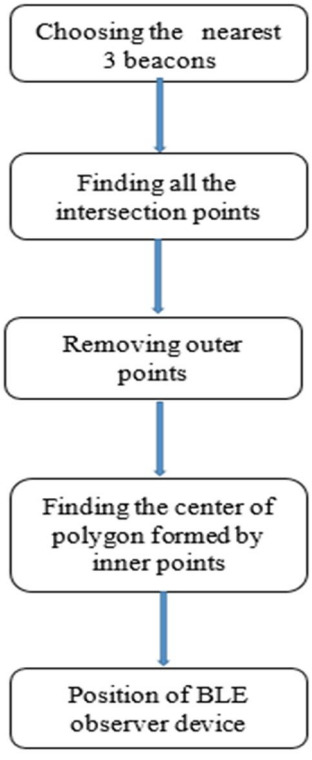

Figure.3. Flow of Enhanced trilateration algorithm

This modified trilateration algorithm, as in the basic algorithm takes the radius and co-ordinates of the three nearest Beacons. Using the information (radius and co-ordinates) algorithm calculates all the intersection points between the circles. This is done by using all pair of circles (circle1 & circle2, circle1& circle3, circle2& circle3), totally 6 intersection points are calculated. In these intersection points, it's required remove some points which are not coming under all three circles (at least at the circumference all 3 circles) which are referred as outer points. After removing these outer intersection points, remaining points are considered as inner points. These inner points intern used to form a polygon. Then calculate the center of the polygon which is the representation of the nearest position of the BLE Device.

Results and Comparison

Basic trilateration will not give correct position co-ordinates whenever it is subjected for the position calculation. Because of small distance error it might leads to large positioning error. Enhanced trilateration method avoids the error in estimated position by doing lot calculation within the limits of circle (i.e. by considering all the intersection between the circles). This process neglects the all the outer points (unwanted points which are not lying under all the circles) by considering only inner points. This leads to minimization of errors caused during the estimation of distance using RSSI in indoors.

Table 1. Result Comparison of Trilateration Algorithms

Trilateration algorithms	Results (actual position x=3.5 and y = 0.6) in m
Basic trilateration	x = 2.7 and y = 0.8
Basic trilateration	x = 1.4 and y = 0.7
Enhanced trilateration	x = 2.9 and y = 0.8
Enhanced trilateration	x = 3.1 and y = 1.0

Table shows the results of basic trilateration i.e. x and y co-ordinates values of BLE device. Actual position of the BLE device is x=3.5 and y=0.6. As the first result x=2.7 and y=0.8 is quite good and is very near to the actual position. But basic trilateration algorithm shows ambiguity while estimation of position since it is not able to find out exact intersection point where all 3 circles meet each other. In the next result, it is observed that large change in the accuracy of positioning just because of ambiguity of basic algorithm. Produces larger errors with the small change in the distance from any beacon. This limits the use basic trilateration algorithm in the industrial basis applications.

Same table shows that enhanced trilateration results which is more accurate than basic trilateration even though errors are present in the distance calculation just because of RSSI instability in indoors. It is also observed that errors in the estimation of position is very less (i.e. less than 1m) and ambiguity while estimating position is also eliminated completely. From the table shown above it is observed that both results of enhanced trilateration are quite near to the actual position of the BLE device.

Results of position calculation are showed in python canvas in figures 4 and 5 as shown below. From the Fig. 4 it is observed that the error is very large even in this smaller area. This algorithm works even in the absence of advertisement of some Beacons (with detection of even two beacons also) with very less errors when compared to basic trilateration algorithm. Miscellaneous errors are completely removed by this algorithm.

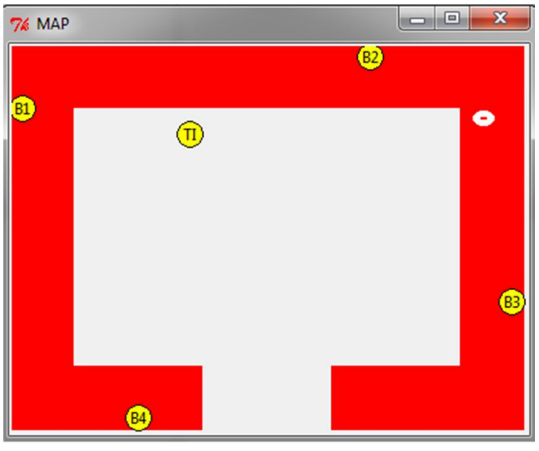

Figure.4. Canvas showing 2D map of trilateration results

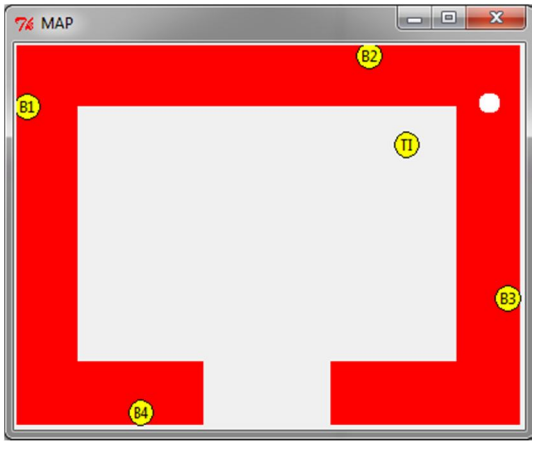

Figure.5. Canvas showing 2D map of trilateration results

Conclusion

As per the Results it is confirmed that use of Basic Trilateration algorithm will definitely reduce the accuracy in the positioning and sometimes generates larger errors. And also shows how the Enhanced Trilateration increases the accuracy by considering simple modification and use of mathematics. Eliminates miscellaneous errors that causes to generate negative axis values which cannot be shown on the Python Canvas Map since in the map x and y starts from 0. So by considering the fact of placement and applying Enhanced Trilateration will definitely reduce the errors in the indoor positioning.

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