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RSSI BASED BLUETOOTH LOW ENERGY INDOOR POSITIONING

Abstract. People usually spend time inside buildings like offices, shops, hospitals, airports, train station and other indoor spaces. Nowadays, the task of positioning and navigation in this kind of environment is becoming more relevant and useful. Commonly used GPS (Global Positioning System), which is typically used in obtaining location information, has no use in closed spaces. Thereby, we need new technology of real-time location system. In this research work we investigated usage of Bluetooth Low Energy RSSI to estimate location. We experimented with the following mathematical filtering functions to smooth rssi and improve accuracy: median, mode and single direction outlier removal. For position calculation, we used trilateration algorithm. Our research based on assumptions and experiments of works of other researches. The goal was to achieve accuracy of 1-2 meters.

Keywords: Internet of Things, trilateration, localization, RSSI, Bluetooth Low Energy.

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Аннотация. Люди обычно проводят время в зданиях, таких как офисы, магазины, больницы, аэропорты, вокзалы и другие закрытые помещения. В наше время, задача позиционирования и навигации в такого рода окружении становится более значимой и нужной. Широко используемый GPS (Global Positioning System), который обычно используется в получении информации о местонахождении, не применяется в закрытых помещениях. В связи с этим, нам требуется новая технология системы позиционирования в режиме реального времени. В данной исследовательской работе мы исследовали использование Bluetooth Low Energy RSSI для расчета местоположения.

Мы провели эксперименты со следующими математическими фильтрами для выравнивания RSSI и улучшения точности: медиана, мод и метод удаления одного направления. Для расчета местоположения мы использовали алгоритм трилатерации. Исследование основано на предположениях и экспериментах, раскрытых в работах других исследователей. Целью было – достичь точности установления местонахождения человека в 1-2 метра.

Ключевые слова: Internet of Things, трилатерация, локализация, RSSI, Bluetooth Low Energy.

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Түйіндеме. Адамдар көп уақытын офис, дүкен, аурухана, аэропорт, вокзал сияқты жабық ғимараттарда өткізеді. Біздің заманымызда қоршаған ортаның осы түрін позициялау және навигациялау маңызды және қажетті бола түсуде. Орналасқан жері туралы ақпарат алу үшін жиі қолданылатын GPS (Global Positioning System) жабық кеңістікте пайдаланылмайды. Осыған байланысты нақты уақыт режимінде позициялау жүйесінің жаңа технологиясы қажет. Осы зерттеуде біз орынды есептеу үшін Bluetooth Low Energy RSSI-ті пайдалануды зерттедік. RSSI-ні біріктіру және дәлдігін жақсарту үшін келесі математикалық сүзгілермен эксперименттер жүргізілді: медиана, мод және бір бағытты жою әдісі. Орналасқан жерді есептеу үшін трилатерация алгоритмін қолдандық. Біздің зерттеулеріміз басқа зерттеушілердің жұмыстарында табылған болжамдар мен эксперименттерге негізделген. Мақсатымыз 1-2 метр дәлдікке жету болды.

Түйінді сөздер: Internet of Things, трилатерация, локализация, RSSI, Bluetooth Low Energy

Introduction

Buildings nowadays became bigger, more complex and full of different things, from various kind of spice in grocery store to branches of gates in airports. The necessity of guide through indoor space, which is not simple map, but is a system with updating in real-time client position feature, has grown up. Main items of Real-Time Location Services (RTLS) are [1]:

- basic station – equipment providing reference points with fixed coordinates, according to its coordinates and received signal strength it is possible to identify the position of active label;
- active label – radio electronic device that attaches to the monitoring object and interact with basic station;

- server software – provides management of measurement process, distance and coordinates calculation, processing and accumulation of data.

Bluetooth Low Energy compatible devices, typically called Beacons, were chosen as a basic stations, because of their sufficiently small size, low battery consumption, lower cost. Beacon is based on Bluetooth low energy proximity sensing by transmitting a universally unique identifier picked up by a compatible app or operating system [2] RSSI value used in calculation of approximate distance between beacon and client device. Since beacon transmit radio waves, RSSI value oscillate influenced by absorption, interference and diffraction effects. In this case, it should be implemented special filter to make RSSI amplitude lower. Authors in work [3] mentioned that beacons abilities such as durability, mobility and high reaction time – have led to Bluetooth BLE technology replacing Wi-Fi for positioning purposes.

Trilateration algorithm was chosen for coordinates calculation due to its simplicity in understanding and implementation. It depends on the amount of beacons, which must be three.

This research mostly based on work [3].

1. Related works

Main questions about RTLS using beacons concerns the reliability of beacons' RSSI in distance calculation and compatibility of geometric algorithms. The result of work [4] shows that the RSSI technology gives an unacceptable high error and thus is not reliable for the indoor sensor localization. The reasons are such signals characteristics: signal attenuation, signal interference and multipath propagation [3]. Attenuation occurs when signal pass through objects, as a result strength of signal become weaker. RSSI and distance have inverse proportional dependence. Interference caused by interferences between other wireless signals. Multipath is a signals receiving through their multiple collisions.

However, beacon still has advantages and special calibration must be done with RSSI values. Authors of works [5-6] have mentioned the median values of RSSI, which is the middle of sorted array of numbers. We also considered the mode value, or modal value, which is the most repeated RSSI among the set of received values. Work [7] presents algorithm of single direction outlier removal. Authors used mean and standard deviation values, calculated from last ten RSSI of a sequence of received signals, to create a threshold RSSI value. Finally, only RSSI that passed threshold used in further calculations.

The next question about RTLS is an algorithm for positioning calculation. Work [3] proposed the trilateration algorithm, which needs coordinates of basic stations and distance to them from active labels. Using RSSI we can calculate approximate distance from Beacons to smartphone and we will also know position of Beacons. In work [7], author used triangulation algorithm, which is very similar to previous one, except the usage of triangle's centroid. The last figured out algorithm, fingerprint, was examined in work [8]. It uses probability distributions to generate fingerprint map of indoor space. We have chosen the algorithm from work [3], trilateration, because it is easier to implement and it can simply work in 2D coordinates. Comparing with trilateration, triangulation needs to know more information about receiving angle and need more research on Beacon's antenna behavior.

2. Methods

During the research, we designed a client-side application for Android operating system and server-side application. Client-side application communicates with bluetooth devices, calculates RSSI and forwards data to server-side application. Server-side application receives data from mobile application, store meta-data into database and perform further calculations to get coordinates and to improve accuracy.

Next sections describe formulas and algorithms that we implemented on server-side application.

2.1 RSSI and distance relation formula

From work /3/ we got the formula for RSSI based distance calculation.

$$RSSI[dBm] = -(10n\log_{10}d - Tx) \qquad (1)$$

where RSSI is an obtained RSSI value, Tx is a transmission strength in a distance of one meter, n is an attenuation constant, d is distance between transmitter and receiver. From formula 1, we can calculate distance with obtained RSSI, but we also need to know n and Tx. Tx is a defined value, which Beacon transmit in its meta-data and set by manufacturer. In our experiments we used Beacons with Tx = -74 dBm. Attenuation could be calculated experimentally on defined set of distances. However, some researches /7, 9/ use common coefficients, despite the possibility of increasing inaccuracy. Filtered RSSI was used in calculation. Filtering we will describe further.

2.2 RSSI filtering

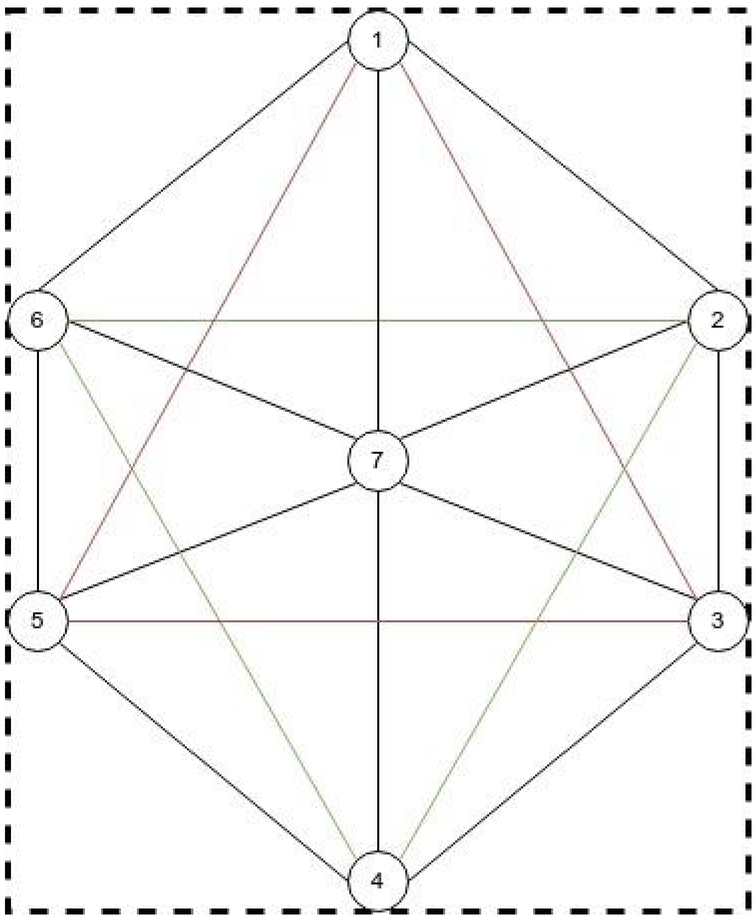
Server part accepts RSSI list and proceed with main calculations. As we mentioned before RSSI needs filtering due to its instability. During this research work, we have implemented three RSSI filtering methods: mode, median and single direction outlier removal (SDOR).

- Mode method counts occurrences of each RSSI value and finds RSSI with maximum occurrences.
- Median method sorts all RSSI values at first, then it chooses RSSI in the middle of the list.

- SDOR presented in work /7/ uses ten recent RSSI values to calculate threshold. Their mean (rssi_mean) and standard deviation (rssi_std) of these ten RSSI are calculated. Any RSSI that is below (rssi_mean - 2*rssi_std) is removed from the stored RSSI. Then the average value of the remaining RSSI, rssi_p, is the pre-processed RSSI and used in future process.

2.3 Trilateration and coordinates calculation

The beacons are located in a room as shown in picture 1. Smartphone with client-side appplication moves around the room. The application passes RSSI list to server at every second. Beacons located in a form of hexagon, taken from work /3/. We examine eight triangles by trilateration algorithm. In picture 1, Beacons represented as circles with numbers.



Pic.1. Room plan with Beacons location

To calculate distance we use formula 1 and estimated attenuation values. Now we can use trilateration algorithm. Trilateration is a technique that calculate the intersection point of three circles. Our Beacons represented as circles with distance to them as a radius. The coordinates of smartphone could be calculated via the construction of three equations for each circle:

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

In theory, if distance to each Beacon is correctly defined, we can get accurate coordinates of the smartphone. Since we have eight triangles, created by Beacons, we have to get one point coordinates from eight possible points. For this purpose, authors of work /3/ implemented Center of Gravity(COG) algorithm. During experiments we have noticed, that not accurate distance cause insufficient work of COG., because we got significant amount of points that were outside of the map. Finally, we decided to use method of centroid calculation, which is a simple calculation of average for x and y.

3. Tests and Results

During experiments we used 7 Beacons. Characteristics of used devices presented in Table1.

Table 1

Devices characteristics.

Beacon	CSR H13323v1 1010 IC with size EEPROM SPI programming connector PCB antenna User pushbuttons RGB LED User slide switch Power switch AA holders on reverse
Smartphone	Sony Xperia XA1 Bluetooth 4.2

3.1 RSSI and distance relation formula

Table 2 shows the results of attenuation, calculated in different distances. We calculated attenuation on each meter from two to seven. Sometimes we got different RSSI values in one distance. For example, on distance of 2 meters we got RSSI -58dBm and -59dBm. We considered such cases.

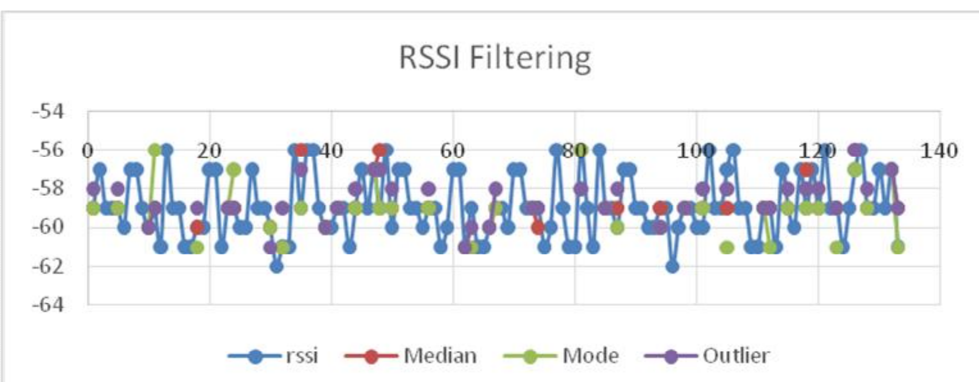
Table 2

Signal attenuation constants measured experimentally

distance	attenuation (n)	RSSI
2	-5.31508	-58
2	-4.98289	-59
3	-2.934264	-60
3	-2.72467	-61
4	-1.82706	-63
5	-1.4306	-64
6	-1.156587	-65
6	-1.028077	-66
7	-0.828306	-67

3.2 RSSI filtering

During experiments, we have noticed that single direction outlier removal algorithm works better, because it has less amplitude than other examined techniques. Picture 2 shows the comparison between real received RSSI values and filtered values. Every seconds smartphone passes data to server-side, where calculation held. SDOR algorithm showed better results than median and mode, and it was selected for main positioning experiments, described in part 3.3.

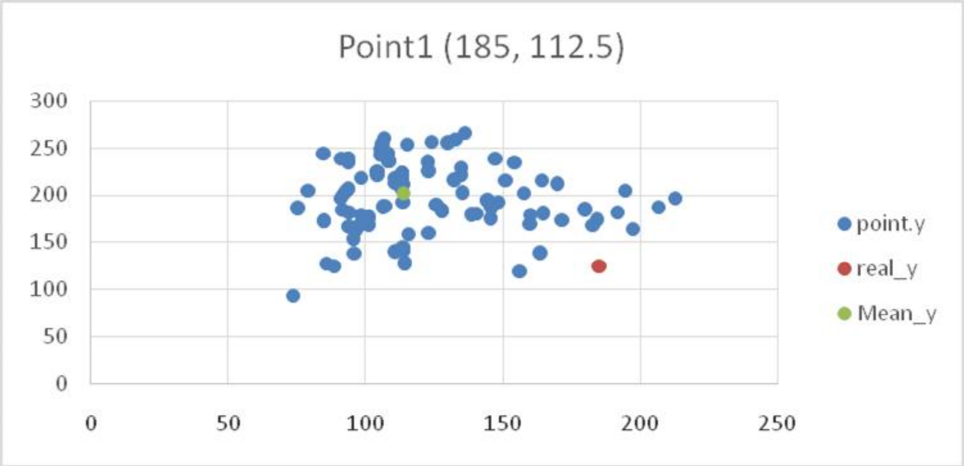


Pic.2. Graph of RSSI and its filtered values

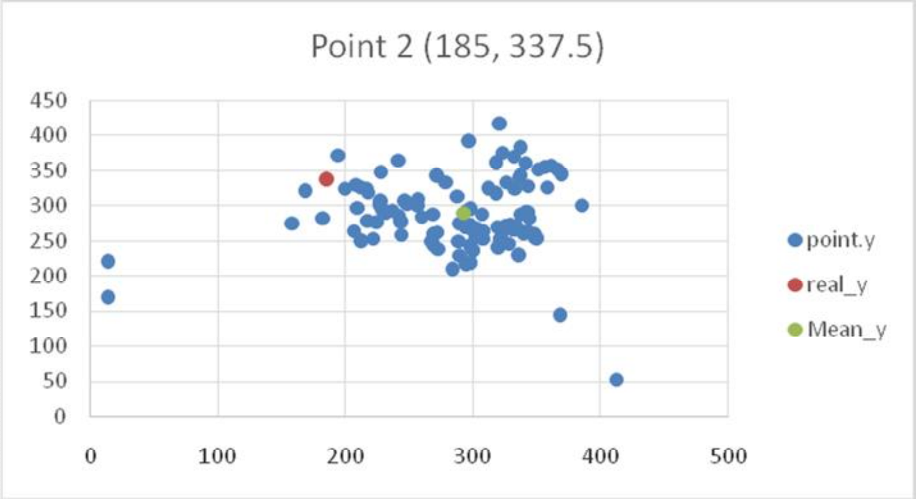
3.3 Trilateration and coordinates calculation

For experiments, we used empty room without obstacles and furniture. Size of the room is 7.40:9 m, we scaled this room into schematic image of size 370:450 pixels. Further, all sizes imply pixels.

Calculations were made for two points with coordinates (185,112.5) and (185, 337.5). COG and Centroid method were tested in final point determination. COG has shown very bad results, because calculated point was mostly outside the map. In final calculations, we used Centroid method. Results are shown in picture 3, 4. Blue points represent calculated points during 5 minutes. Red point represent actual coordinates of smartphone.



Pic.3. Results for Point1



Pic.4. Results for Point2.

Gray point is a Mean value among all calculated positions. We used distance between Mean of calculated points and actual position point as accurate index. For both point it was near 2 meters.

Comparison of RSSI filtering algorithm, in picture 2, shows SDOR as the best filter among presented. However, we will look further for more accurate RSSI filtering, because it is the main issue in our research work. It is seen that the spread of RSSI is very wide. Picture 2 shows RSSI jumps by 10 points, under the conditions that the smartphone and devices are in place. Results on RSSI value prove estimation of /4/ that RSSI could be not reliable for localization purpose. Picture 3 and 4 shows spread of estimated coordinates after filtering. We can conclude that we achieve accuracy up to 2 meters.

Conclusion

In this research work, we have examined RSSI based Bluetooth low energy indoor positioning. Implemented three filtering algorithms: median, mode and single direction outlier removal (SDOR). Coordinates calculation held by trilateration and centroid algorithms. We can conclude that RSSI based Bluetooth low energy indoor positioning depends on several conditions, which make whole work complex from mathematical point of view. Firstly, smartphone as active label make RTLS dependent on its signal receiving capability. Substituting of defined smartphone to another one leads to accuracy fault, because of the attenuation coefficients change. Secondly, it is needed to make deep research on Beacon. During experiments, it was noticed that after 7-8 meters, RSSI values start to increase and then again going down. Thirdly, attenuation was calculated at each meter from two to seven, as a result we could not expect accuracy more than one meter. However, system showed the ability to define certain contour for active label. Implementation of more accurate filters could probably improve localization system. On the other hand, more calculations with basic stations results in RTLS inflexibility for adding new Beacons. In future work, we would like to apply machine learning for coordinates' calculations. Basic idea is to create model with principle of relativity between RSSI values to each basic station such that for each set of RSSI relativity there will be certain point in plane.

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