Bluetooth-based WKNNPF and WKNNEKF Indoor Positioning Algorithm

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***Abstract*—Indoor Positioning System (IPS) in generally perform as a network of devices that always located the objects or people inside a building wirelessly. An IPS has direction relies nearby anchors and also can be entirely local to your smartphone. With the rapid growth and sharp increase in Indoor Positioning System (IPS) demand in the world, there are a lot of researchers trying to invent new algorithm to develop IPS. This paper proposed the Bluetooth-Base Indoor Positioning Algorithm. The RF characteristics such as RSSI and WLAN RSSI fingerprinting system normally formed by two phases, fist is offline phase and second is online phase. Fingerprinting system handling both off-line and online data and estimate the user's location. Our algorithm design is a collection of Weighted K-Nearest Neighbors (WKNN) and Filtering algorithms by KALMAN Filter. Finally, to avoid the problems of IPS and get a better accurate we proposed two algorithms: Weighted K-Nearest Neighbors Particle Filter (WKNNPF) and Weighted K-Nearest Neighbors Extended Kalman Filter (WKNNEKF) compare to KNN and WKNN result. After comparing we found that the result of WKNNPF and WKNNEKF is better result than KNN and WKNN. The Probability in 3M of WKNN is about 79%, WKNNEKF is about 89%, and WKNNPF is about 95.1%. Among one of the proposed algorithms WKNNPF is better than WKNNEKF on accuracy 1.7-2 meters with 42.2m/s response time.**

Keywords*—Indoor Positioning System (IPS); Bluetooth low energy; WLAN; RSSI; WKNNPF; WKNNEKF; KNN; WKNN

I. Introduction

In present, indoor positioning system became more interested and more advantages for the people in the world. Many applications that we have seen some papers introduced in field of m-commerce that based on the principle of the well-estimated location of the various customer as well as in wireless network sector. For example here, it is talking about advertising in large stores or guides in museums which using modern portable devices is possible, in case if we estimate the exact location of a mobile terminal in every single time. Moreover, an automated delivery developed procedure, which is the method based on the user location is also necessary in term of to provide quality service in the area of wireless network, especially in condition of overweight shipments [1].

Bluetooth certification which is developed and manufacturing by the Special Interest Group (SIG) has widely point the technology that suitable for future use in the home or any indoor environment [2][3]. Hence, the totally proposed ideas of this paper was notice about the challenge with all of the issues faced in location estimation plus with the general evaluation criteria which focus on a Bluetooth-based indoor positioning system as well. Although, we can realized that the Location estimation take place in a mobile terminal without any changes of the values in the geometry network zone. The system developed as usual and it's based on a well-known and well-publicized of the triangular method by using the theoretical of received signal strength of the surrounding environment of the Bluetooth access point we have.

Anyways, to obtain precise position estimation, we must determine the dependence between distance and the received signal strength by specific condition carefully. Especially in indoor areas, some relevant boundary conditions, like make use of equations reflection and the wall drying for free as well as propagation impossible. Then, the necessary distance is mainly focus and calculated as well as by an approximate estimate of the received signal strength indicator (RSSI) in simple ways [4][5]. As we known that, the Bluetooth devices of retrieving the actual received signal strength do not provide any interface as well as we want, so our research developed based on this positioning system focus on the point which using the RSSI values that provided as mentioned as in the standard technic to obtain a range estimate between the access point and the mobile terminal as well. Although, this research demonstrated the theory of mathematical system and introduced the mathematical approach by positioning system is based. Our steps start from the beginning with position estimating which mainly based on signal strength using the Least Square

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Estimation (LSE), and then we have converted the RSSI measurement to the distance. After that, the implementation results of the actual test are presented.

II. Related Work

A. The Position Estimation based on Signal Strength

In this part we proposed the related technic which is a part of achieving the result. As shown in below equation, a position estimation method based on signal strength by using LSE is introduced and explain in detail as well.

In the mobile network we assumed N≥2 as the number of a base station and the position of a base station k is defined

by: $\overrightarrow{p_k} = (x_k, y_k)^T, k \in 1..N.$

Hence, the distances $r_i(\vec{x}), r_j(\vec{x})$ between stations i, j and a point in the x-y zone, has given as well as by

$\vec{x} = (x, y)^T$:

$$\begin{cases} r_i(\vec{x}) = \sqrt{(x-x_i)^2 + (y-y_i)^2} \\ r_j(\overrightarrow{x}) = \sqrt{(x-x_j)^2 + (y-y_j)^2} \end{cases} \quad (1)$$

The solution of the system of equation (1) as shown in above section, it causes two possible intersections of the corresponding circles. So, to get a perfect solution to solve this problem, it's importantly to calculate and set the location of the mobile device which based on the distance between the terminal and at least three different base stations among them is included [6]-[9]. Other thing, the single distances also can be obtained as well as by measuring the functional correlation to the signal strength. If the value of the distance between both points, the base station N>2 and the mobile terminal is already known. Otherwise, the location estimate also can be effectively as well by calculated using the LSE method. In numerical operations, this method calculates that point correctly in the x-y field, where the position that provides the least squared sum of the distance to the boundary of all possible parts given by Equation (2) as describe as below.

$$\begin{cases} r_i = \sqrt{(x-x_i)^2 + (y-y_i)^2} \\ r_j = \sqrt{(x-x_j)^2 + (y-y_j)^2} \end{cases}, i, j \in 1..N \quad (2)$$

Boundaries are directly calculated from Equation (3)

$$r_i^2 - r_j^2 = (x-x_i)^2 + (y-y_i)^2 - (x-x_j)^2 - (y-y_i)^2 \quad (3)$$

The position estimation is defined by $\overrightarrow{m} = (\hat{x}, \hat{y})^T$.

$$H \cdot \overrightarrow{m} = C \quad (4)$$

With

$$H = \begin{bmatrix} h_{x(2,1)} & h_{y(2,1)} \\ h_{x(N,1)} & h_{y(N,1)} \\ h_{x(N,N-1)} & h_{y(N,N-1)} \end{bmatrix}_{\binom{N}{2} \times 2}, \overrightarrow{m} = \begin{bmatrix} \hat{x} \\ \hat{y} \end{bmatrix}, C = \begin{bmatrix} C_{2,1} \\ C_{N,1} \\ C_{N,N-1} \end{bmatrix}_{\binom{N}{2} \times 1}$$

And
$$\begin{cases} h_{x(i,j)} = 2(x_j - x_i) \\ h_{y(i,j)} = 2(y_j - y_i) \\ C_{i,j} = r_i^2 - r_j^2 + x_j^2 - x_i^2 + y_j^2 - y_i^2 \end{cases}$$

Hence, below is the formula of location estimation of the terminal:

$$\overrightarrow{m}^T = (H^T H)^{-1} H^T C \quad (5)$$

B. The Approximation of RSSI Measurements

This section talked about the way of converting the signal strength measurement into distances between shape of a sender and receiver in the free fields. Below is the equation (6) [10]:

$$s(\vec{x}) = c(d(\vec{x}))^{-\alpha} \quad (6)$$

Variations of signal propagation in indoor areas normally caused by dimming and reflection are strongly considered in easy way as well as by equation (6). Because there is no line of reflection and attention, this happened because those holding Bluetooth device obtain signal propagation in the empty which not suitable for indoor area. Hence, according to reason above we chose to estimate the correlation between signal strength and distance by focusing on on the measurement to improve our estimation as well. Bluetooth specification at that moment didn't release the possibility to extract signal directly. Consequently, after go through reason above we are using the RSSI values set by the Bluetooth protocol to connect the communication between the sender and the receiver in the network as well as we have shown below [11]-[14]. The RSSI value role as important paly that it is giving the distance between the received signal strength and the optimal receiver power rating, called the gold receiver power status. The definition of a golden power receiver has explained and shown in Fig. 1 below.

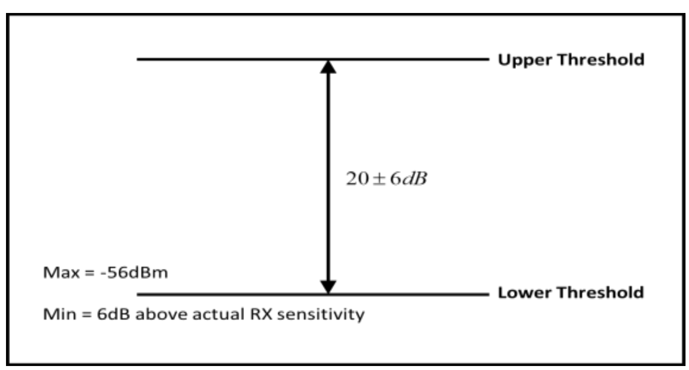

Fig. 1. Golden Receiver Power Rank of the RSSI.

Here, we explain the Fig. 1 above about the golden receiver power status about it working principle. It is determined by two levels which describe below [15][16]. First is the low level that noted by the 6dB to the actual the receiver and maximum of this value mentioned by -56dBm. Second is the high level is 20dB on the low one. It provided accuracy of the upper threshold and the noted with the value is about ±6dB. Hence, we can assume S assigned the received signal strength and the value of S is noted by:

$$S = RSSI + T_0, for RSSI > 0$$
$$S = RSSI - T_{u,} for RSSI < 0$$
$$T_0 = T_u + 20dB \quad (7)$$

Where: T_0 : Upper Threshold

T_u : Lower Threshold

Normally, pursuant to the definition of a gold recipient rating determines the RSSI to distance conversion. Although, if the value of RSSI is within the range of the golden receiver defined by zero, it's mean that, there is no special function can be estimated as well as we can [17]. Therefore, only measurements that provide result in a positive range of RSSI could be considered and granted by functional estimation. Then we can achieve the estimate result by the parameterization in suitable function we chose:

$$y = c \ln x + b,$$
$$y = c_0 + c_1 x + c_2 x^2$$
$$y = c_0 + c_1 x + c_2 x^2 + c_3 x^3 \quad (8)$$

III. Methodology

Our research methodology used the Bluetooth positioning system model to provide a user interface as well as separated into three levels. The indoor area under consideration is covered by the x-y is the first stage of preparation phase, then RSSI function is covering to the environmental conditions which can estimated as well. Hence, the last part of our solution we used the location method to determine the mobile terminal location by dealing based on the RSSI estimation measurement. In this relation, we are mainly focus on the triangular method in term of mathematical calculations in above section by calculation RSSI values of three entry points. Below is the flowchart of the matching process which mentioned as Fig. 2, it is detail and overview of the operational analysis.

In addition to improve the fingerprint method (RSSI), our algorithm design is a collection of Weighted K-Nearest Neighbors (WKNN) and Filtering algorithms (KALMAN Filter). Other thing, to avoid the problems of IPS and get a better accurate we proposed two algorithms are WKNNEKF and WKNNPF.

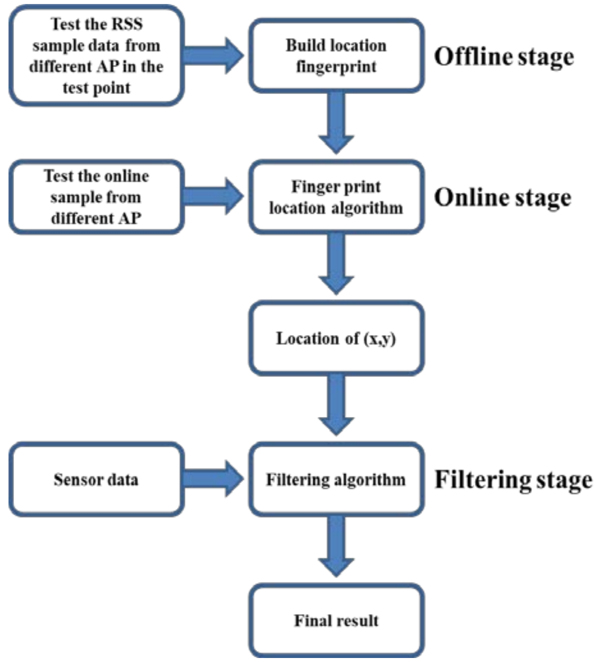

Fig. 2. Flowchart of the Matching Process.

The access points have been assigned and share in a laboratory room of school of information and communication engineering, Guilin University of Electronic Technology. That room is a computer room with a size of 12 x 21m which is shown in Fig. 3.

In this experiment we have done carefully. We were recorded several times of the distances of the randomly selected sections to archive a good approximation function between the RSSI and the single access point as well as we can. The average results among of all measurements which belonging to a segment and access point may generate the RSSI reference value per segment. In our scenario, we can realize from Fig. 2 and 3 and we can explain that the RSSI values of all access points are best equipped with the polynomial function of the order 3. The positioning algorithm has been implemented in MATLAB.

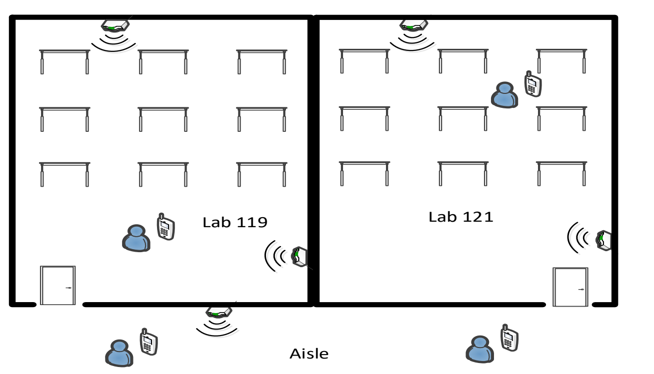

Fig. 3. Indoor Environments Experimental.

IV. RESULTS AND ANALYSIS

According to the experiment methodology, we separated results with 3 different algorithms are WKNN Algorithm in Fig. 4, WKNNEKF Algorithm in Fig. 5, WKNNPF Algorithm in Fig. 6.

After we got the results in each algorithm of Fig. 4, 5, 6. We found that the accurate point of WKNN algorithm is bigger than WKNNEKF and WKNNPF algorithm, and the accurate point of WKNNEKF algorithm is smaller than WKNN and bigger than WKNNPF. And the last one is the accurate point of WKNNPF algorithm is smaller than WKNNEKF and much smaller than WKNN so far. Moreover, we have compared the cumulative probability of the positioning error to find the best performance of each algorithm in Fig. 7. Those algorithms mentioned in three difference colors. Red stand for WKNN algorithm, green stand for WKNNEKF algorithm and blue stand for WKNNPF.

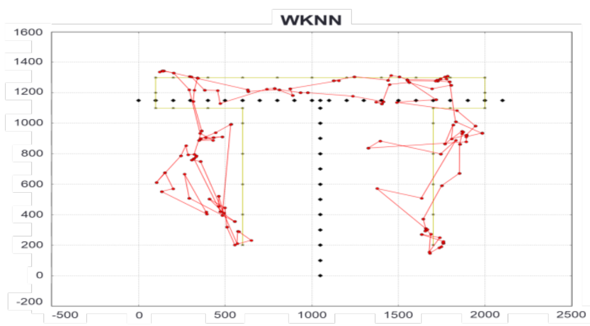

Fig. 4. WKNN Algorithm Result.

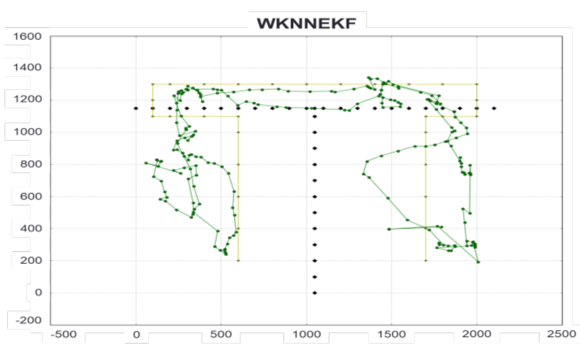

Fig. 5. WKNNEKF Algorithm Result.

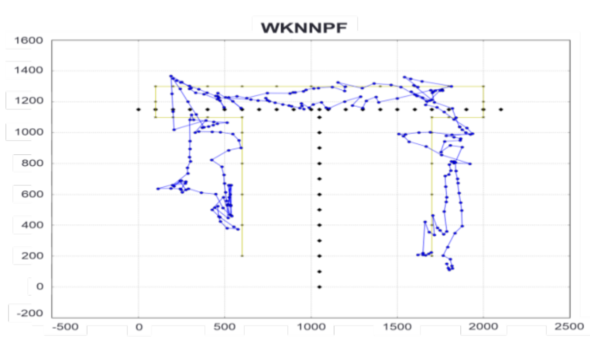

Fig. 6. WKNNPF Algorithm Result.

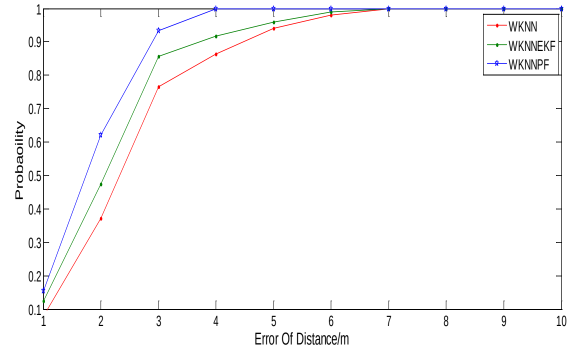

Fig. 7. Errored of Distance/m.

TABLE I. THE PROBABILITY IN 3M

Algorithm	***Mean derivation***	***Minimum derivation***	***Maximum derivation***	***The probability in 3M***
WKNN	3.2m	1.2m	3.8m	79.0%
WKNNEKF	2.5m	0.92m	3.0m	89.0%
WKNNPF	2.0m	0.22m	3.0m	95.1%

The result in Fig. 7 and Table I shows that the probability in 3M of WKNN is about 79.0%, the probability in 3M of WKNNEKF is about 89.0% which is better than WKNN about 10%, and the probability in 3M of WKNNPF is about 95.1% which is better than WKNN about 16.1% and WKNNEKF about 6.1%. It's mean that the proposed algorithm WKNNEKF is better than WKNN and the proposed algorithm WKNNPF is better than WKNNEKF. After we found that WKNNPF algorithm is the best algorithm among the proposed algorithm in this paper, we try to find the algorithm response time of WKNNPF algorithm performance. Then we found that WKNNPF response time is 42.2m/s as shown in Fig. 8 below.

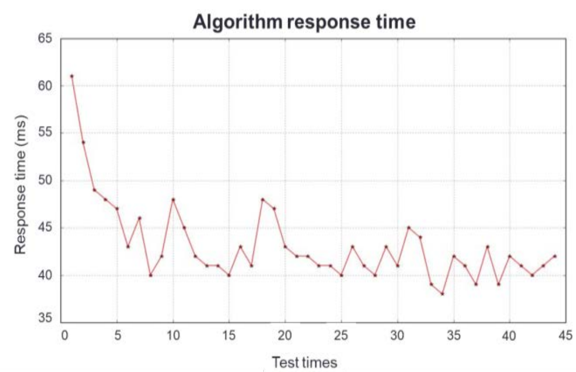

Fig. 8. WKNNPF Performance.

V. Conclusions

In this paper, we carefully experimented with both theory and practice to apply indoor location algorithms. As we all know, there are many previous documents describing IPS with different ways and solutions. Most of them focus on wireless sensors to develop their new algorithms. In a similar way, this paper proposes to study of the Bluetooth-based Indoor Positioning Algorithm. Based on RF characteristics such as RSSI and WLAN RSSI fingerprinting system normally consists of two phases, offline phase and online phase. Fingerprinting system handling both off-line and online data and estimate the user's location. Our algorithm design is a collection of Weighted K-Nearest Neighbors (WKNN) and Filtering algorithms by KALMAN Filter. Finally, to avoid the problems of IPS and get a better accurate we proposed two algorithms: WKNNPF and WKNNEKF which get the better result than KNN and WKNN, and one of the proposed algorithms WKNNPF is better than WKNNEKF on accuracy 1.7-2 meters with 42.2m/s response time.

Acknowledgment

First of all, I would like to thanks to supporter including resources and experiment place. This research can't complete without their support. This work was fully supported by three departments, first is school of information and Communication Engineering of Guilin University of Electronic Technology offered funds and place for experiment and second is the National Natural Science Foundation of China (Nos. 61562016, 61702129, 61772149, and 61320106008) provided software and technic, and third is Guangxi Key Laboratory of Intelligent Processing of Computer Images and Graphics (No. GIIP201703) offered funds and the ideas of algorithm.

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