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Comparison of Multilateration Methods Using RSSI for Indoor Positioning System

Tong Li[1†], Sijie Ai[2], Shigeyuki Tateno[3], and Yuriko Hachiya[4]

[1-3]Graduate School of Information, Production and Systems, Waseda University, Kitakyushu, Japan
[1](kaffer.p.lee@ruri.waseda.jp@waseda.jp)
[2](eyresj@akane.waseda.jp)
[3](tateno@waseda.jp)
[4]School of Health Sciences, University of Occupational and Environmental Health, Japan
[4](hachiya@med.uoeh-u.ac.jp)

Abstract: Recently, as the indoor positioning technologies have been developed continuously, several indoor positioning methods have been proposed and experimented. A previous research has proposed a statistical access point selection method using a kernel density estimation (KDE) based on received signal strength indicator (RSSI). However, the proposed method is only test through a small area experiment, where the movement of the people beside the experimenters is not so much. In this paper, to analyze the stability of the proposed method under noisy environment, an experiment in a daily healthcare facility work place, where the human movement is more complex, is designed; to analyze the effectiveness of the method, several others multilateration methods are compared with the KDE method. The experiment results show the effectiveness and stability of the proposed method.

Keywords: received signal strength indicator, multilateration, kernel density estimation.

1. INTRODUCTION

As wireless communication network technologies are widely developed, and smartphones are becoming a necessary part of daily life, a usage of indoor positioning systems is growing significantly in healthcare facilities such as a retirement home, a sanatorium, and so on. Several positioning technologies using in different situations have already proposed: a global positioning system (GPS), which mainly works outside; an IC tag, a radio frequency identification (RFID) tag, and a beacon, which support very short communication range limited in a small area; and a received signal strength indicator (RSSI) based ZigBee [1-8].

The RSSI, which represents the power of received radio signal from a transmitting device, is a kind of typical distance measurement technique. Through collecting the RSSI value, the distance between a transmitter and a receiver can be calculated. Through using this distance, the position of a unknow node can be determined under a range-based positioning algorithm, such as a trilateration [9,10].

Among the positioning systems, a RSSI based positioning system using ZigBee is proposed [8]. It experimented an access point selection method to improve the positioning accuracy above the weighted trilateration method, through utilize more access points. Thus, the effect of abnormal results can be weakened. This previous research also compared two statistical methods based on the access point selection method, the centroid method and the kernel density estimation (KDE) method. Experiments are designed and shown that the KDE method under a special access point selection method preforms better in term of the maximum and the standard deviation of the positioning error. However, the experiment in this previous research is not complex enough to show the effectiveness of the proposed method; more comparison with other multilateration methods are also needed.

In this paper, to analyze the effectiveness of the proposed method, a more complex real-time filed experiment in larger range is designed; several others multilateration methods are also compared with the KDE method. The experiment is designed in a work place of a healthcare facility, with two staff of the work place as the experimenters.

2. SYSTEM INTRODUCTION

To test the proposed methods, a remote monitoring system same as the previous research used is designed. In the system, for positioning calculation, Zigbee devices are used to gather the RSSI values. Using the RSSI, position results are calculated under different multilateration methods, one is the traditional trilateration (TRI) method, one is a weighted average (WAV) method, one is the previous proposed KDE method with statistical access points combination, the other is a least squares (LSQ) method. The calculation is occurred in real time in the field experiment.

2.1 Hardware

The Zigbee devices used in this paper are developed by Digi International, Inc. (Digi) [11]. These devices are work on 2.4 GHz frequency band, the same as the Wi-Fi, and a maximum data rates at 250 kbps. The greatest feature of these devices is that a mesh protocol named DigiMesh is supported, which has no hierarchy and all nodes are equivalent.

The devices in a DigiMesh network are named routers. The differences between a DigiMesh network and a ZigBee network are: a DigiMesh network needs no coordinator, which is necessary for network formation in

† Tong Li is the presenter of this paper.

a ZigBee network; a DigiMesh network supports a low-power-consumption mode through setting the routers into temporary sleep, which is not allowed in a ZigBee network; the DigiMesh is also reported prefer better in term of the network construction speed and packet lost rate [12]. These characteristics show that DigiMesh network has better suitability, robustness, and performs better in long-term monitoring using.

2.2 Positioning algorithms

In the calculation of this research, two multilateration methods are chosen, one is the previous KDE method, which firstly using the RSSI values to calculate distance, then calculated estimated point through weighted trilateration methods, and finally estimated the position result through a combination of access point selection under the KDE, a WAV, and an LSQ.

2.2.1 RSSI and log-distance path loss model

An RSSI represents the strength of received radio signal in dB (mW). The relationship between an RSSI and a distance could be described by the log-distance path loss model [13], [14] as shown in Eq. (1), and Eq. (2) is the transposition of Eq. (1):

$$R = A - 10N \log_{10} d, \tag{1}$$

$$d = 10^{\frac{A-R}{10N}}, \tag{2}$$

where R presents the received RSSI data, and d presents the distance between the target and the RSSI received access point, N represents the path loss parameter which reflects the environment, and A represents the received signal strength at the reference distance. In the previous research, an experiment reported that when A is smaller than -44 dB (mW) and N is larger than 2.2, the results are stable [8]. However, during the pre-experiment of this research, a noisier environment is reported, to reduce the influence of the noise, in this paper, the parameter A and N is set -60 dB (mW) and 3, respectively.

2.2.2 Statistical access point selection method

After the distance calculation, the weighted trilateration is used to calculate the position of the access points. Trilateration is one of the most widely used algorithms in positioning [15-17], which determined the target position as the intersection point formed by three circles formed from three access points. An ideal situation of the intersection point formation is shown as Fig. 1,

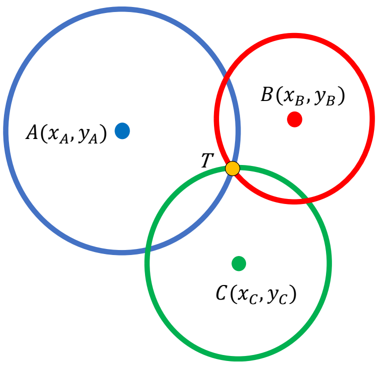

Fig. 1 Trilateration method in an ideal situation.

where the three circles form only one intersection point. Under this situation, the position of the intersection point can be calculated through Eq. (3). where the centers of the three circles O_A, O_B, and O_C, are $A(x_A,y_A)$, $B(x_B,y_B)$, and $C(x_C,y_C)$, respectively. The distances between the target point $T(x_t,y_t)$ and A, B, and C are calculated by Eq. (2) and recorded as d_A, d_B, and d_C, respectively. Calculation under several unideal situation is also discussed in [8] and [18].

$$\begin{aligned} (x_1 - x_A)^2 + (y_1 - y_A)^2 &= {r_A}^2, \\ (x_1 - x_B)^2 + (y_1 - y_B)^2 &= {r_B}^2, \\ (x_1 - x_C)^2 + (y_1 - y_C)^2 &= {r_C}^2. \end{aligned} \tag{3}$$

To reduce the signal noise, access point selection is added to choose access points using for KDE calculation under different combination rules. A top-6-combination, which only select the combinations with the top-6 RSSI values formed access points, is reported having better performance in term of accuracies. However, during the pre-experiment of this research, a lack of usable access points is reported, to ensure the number of the access points is enough for the KDE calculation, all-combination which select all the probable combinations is chosen in the filed experiment.

A KDE is finally used to estimate the positioning result from the selected access points. The kernel density estimation (KDE), also called the Parzen-Rosenblatt window method named after Emanuel Parzen and Murray Rosenblatt [19,20], is a non-parametric method to estimate the probability density function of random variables. The kernel density estimator $\hat{f}_h$ of a univariate independent and identically distributed sample (x_1, x_2, …, x_n) with an unknown density f is calculated through Eq. (4):

$$\hat{f}_h(x) = \frac{1}{n}\sum_{i=1}^{n} K_h(x - x_i) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x - x_i}{h}\right), \tag{4}$$

where K presents the kernel function, and K_h presents the scaled kernel. To yield meaningful estimates, the kernel function should satisfy the following [19]:

$$\begin{cases} \sup_{-\infty<u<\infty}|K(u)| < \infty, \\ \int_{-\infty}^{\infty} |K(u)|du = 1, \\ \lim_{u\to\infty}|uK(u)| = 0. \end{cases} \tag{5}$$

The most commonly used kernel function is the Gaussian kernel function:

$$K(u) = \frac{1}{\sqrt{2\pi}} exp\left(-\frac{1}{2}u^2\right). \tag{6}$$

A density distribution results are shown as Fig. 2. The peaks in Fig. 2 is considered the positioning result in this paper, since this point has the highest possibility of density distribution.

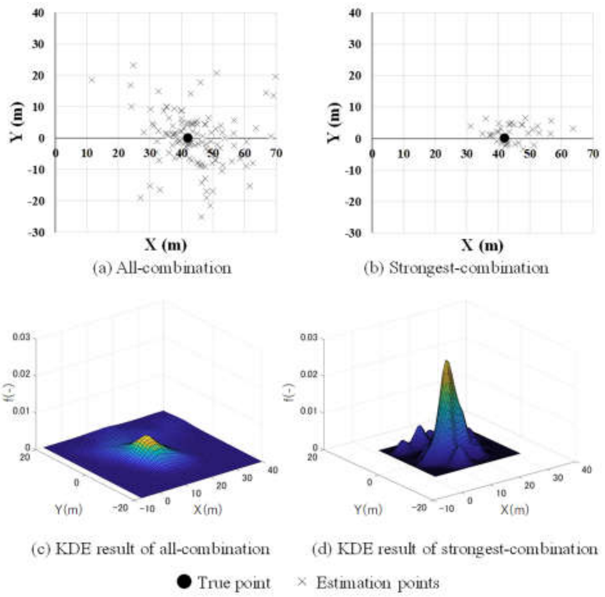

Fig. 2 Kernel density estimation schematic diagrams under all combination and strongest combination.

2.2.3 Multilateration weighted average method

The weighted average method is a widely used method for position calculation, which follows the Eq. (7) and (8).

$$T(x_t,\ y_t) = \left(\frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i}, \frac{\sum_{i=1}^{n} w_i y_i}{\sum_{i=1}^{n} w_i} \right), \quad (7)$$

$$w_i = \frac{1}{d_i}, \quad (8)$$

where $T(x_t,y_t)$ presents the target position; w_i presents the weight calculated from the distance d of each access points, the position of which are presented as (x_i,y_i). The advantage of the WAV method is that it can calculate the position result simply. However, the position result will only appear inside a polygon made by the access points. Thus, to use the weighted average method, routers should be set outside the move range of the positioned targets.

2.2.4 Multilateration least squares method

The least squares method is a calculation which minimizes the sum of the squares of the residuals from the results of every single equation [21]. The calculation of this method is shown in Eq. (9):

$$S = \sum_{i=1}^{n} {r_i}^2, \quad (9)$$

where S presents the sum; r_i presents the residuals from the result of equation i. When using in the positioning system of this paper, each single equation will be calculated as the difference between the distance of the tested position with a given access point, and the distance calculated from the RSSI value of that access point. The advanatge of the LSQ method is that the range limit of the WAV method is not existence. However, the position result will be influenced by a extremely noisy data.

3. EXPERIMENT AND RESULTS

In this paper, to test the effectiveness of the previous proposed method, a real-time filed experiment is designed in a healthcare facility. The experiment continued eight hours with five staff carrying the position devices. To analyze the position accuracies, two of the five staff of the work place are chosen as the experimenter, carrying with the position devices. A 30 minutes real-time position experiment is designed. Since the experimenters are keep working and moving, an actual position is difficult to measure. To solve this problem, the experiment work place is divided into several areas, the final position accuracy is decided by whether the result is in the correct area or not.

3.1 Experiment environment

The experiment is designed in the third floor of a four-floor healthcare facility; the experiment field is divided into 38 areas, which is shown in Fig. 3. In this experiment, 15 routers are used for positioning which is shown in Fig. 4, while another two routers are also used to pass the signal to the observation center set in the forth-floor. The RSSI value between the position devices with the positioning routers are collected then transmitted to the observation center. During the real-time experiment, the position is test 30 minutes uninterruptedly. In this experiment, several positioning methods are used, namely, the trilateration method, the WAV method, the KDE method, and the LSQ method.

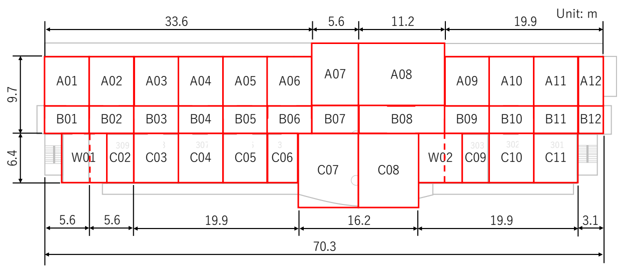

Fig. 3 The area divided of the experiment environment.

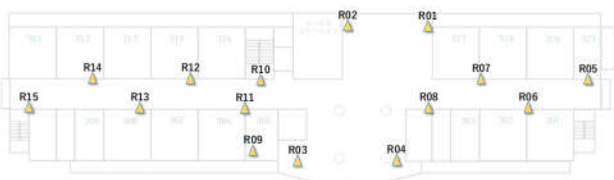

Fig. 4 The router positions of the experiment.

3.2 Pre-experiment results

Since the experiment environment is changed, to test and adjust the need of the field experiment, a pre-experiment is designed. In the previous research, the parameter of A and N is set -42 dB (mW) and 2.2, respectively, following an experiment result [8]. However, the pre-experiment shown that under this environment, the results are not stable until A is smaller than -60 dB (mW) and N is larger than 3. As a result, the parameter A and N is set -60 dB (mW) and 3, respectively.

3.3 Experiment results

The movement of experimenter A is recorded as shown in Fig. 5 and 6. The movement of experimenter B is recorded as shown in Fig. 7. In these figures, the green mark presents the start position, the red mark presents the end position. The reason why the movement of experimenter A is shown in two figures separately, is that the movement of this experimenter is too complex that is hard to arrange in one single figure. In addition, the arriving time at each record is shown with time lag from the start position, in Table 1 and 2, for experimenter A and B, respectively. The position results of these two experimenters are shown in Table 3.

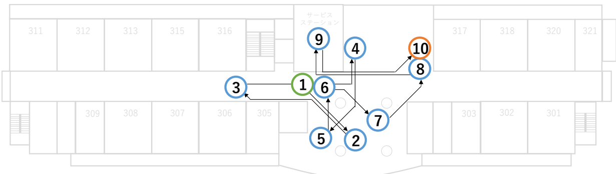

Fig. 5 The first part route of experimenter A.

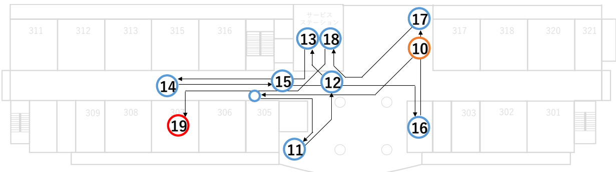

Fig. 6 The second part route of experimenter A.

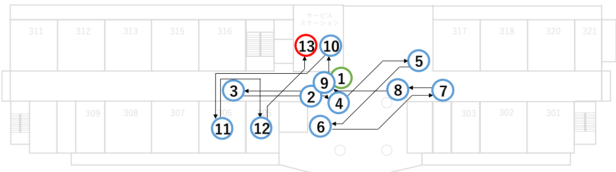

Fig. 7 The route of experimenter B.

Table 1 The time record of experimenter A.

Order of record	Time (min)
1	0
2	3
3	5
4	6
5	7
6	9
7	11
8	12
9	16
10	17
11	19
12	20
13	21
14	22
15	23
16	24
17	25
18	26
19	27

Table 2 The time record of experimenter B.

Order of record	Time (min)
1	0
2	3
3	5
4	6
5	12
6	13
7	14
8	17
9	18
10	26
11	28
12	29
13	30

Table 3 The accuracy result of experimenters A and B.

Experimenter	TRI (m)	WAV (m)	KDE (m)	LSQ (m)
A	52.7%	70.6%	69.2%	67.1%
B	58.7%	78.2%	72.8%	60.7%

The experiment results show that although the usable range of LSQ method is limitless, the accuracy results are worse than the other two methods; although the WAV method always have a better performance in the accuracy results, the setting of the routers is limited; the KDE method, although not performance better in accuracy than the WAV method, it has no router setting limit the same as the LSQ method. Thus, the KDE method performance better when combining both the position accuracy and use limit.

4. CONCLUSION

In this paper, to analyze the effectiveness and stability under daily life environment of the proposed method in a previous research, a real-time filed experiment with more complex human movement in a larger range is designed; a compare with other multilateration method is also designed. The experiment includes two staff of a healthcare facility work place as the experimenters, the position accuracies of the weighted average method, the kernel density estimation method, and the least squares method of experimenter A are 70.6%, 69.2%, and 67.1% respectively; those of experimenter B are 78.2%, 72.8% and 60.7%, respectively. The accuracy results shown that the proposed KDE method has a same accuracy level with the traditional WAV method, considering the limit of the WAV method, the effectiveness of the KDE method is shown. A pre-experiment is also designed, the result of which shows that although an adjustment of the parameter A and N is needed to follow the different environment needs, the influence of the parameter changing is the same as reported in the previous research. For future work, a discussion of whether the result of the KDE method is improvable is needed; more comparison with different multilateration methods and more complex experiment are also needed. Moreover, an improve of the accuracy results is also necessary.

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