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An Indoor Positioning Technique Based on Fuzzy Logic

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***Abstract*—In this paper, a novel fuzzy logic indoor positioning system (FLIPS) is proposed. It measures the distances using received signal strength (RSS) between an object and stations, and then a fuzzy logic inference engine determines coordinate of the object. The proposed fuzzy approach performed better than triangulation technique when the RSS is unstable. The experiments demonstrate the performance of proposed approach within Zigbee sensor network. Moreover, the proposed FLIPS can be easily implemented hardware due to the scheme is low complexity.**

***Index Terms*—indoor positioning, wireless sensor network, received signal strength, fuzzy logic system**

I. Introduction

The global positioning system (GPS) is the most widely satellite-based navigation and time transfer system for determining a position on the Earth's surface by comparing radio signals from several satellites [1]. Traditionally, the GPS provides accurate positioning functions using triangulation method [2] which finds a particular place on earth by the distances between the GPS hand-held receiver and the GPS satellites. Currently, GPS technique is applied for various electronic devices to enable location-based service, such as navigation, tourism, and military applications etc. However, GPS is a line-of-sight transmission method which cannot be used in indoor environment. Compare with outdoor orient GPS, in the indoor environment, the positioning system function also plays important for many applications. Therefore, Indoor Positioning System (IPS) for related applications such as commercial, smart building, public safety, and military raises new challenges for positioning problem.

Furthermore, wireless technologies are available options for developing IPSs in the building, such as wireless local area network (WLAN) [3], wireless sensor network (WSN) [4], radio frequency identification (RFID) [5], Bluetooth [6], etc. Zigbee is one of the popular wireless sensor protocols. It takes full advantage of a powerful physical radio specified by IEEE 802.15.4 [7]. It has been designed to provide features such as low cost, low power consumption, simply implemented and high density of nodes per network. In addition, the IPS can implements a distributed computation algorithm that uses received signal strength indicator (RSSI) values from known reference nodes [7]. The most commonly used techniques for automatic location sensing are scene analysis, proximity, and triangulation [8][9]. Firstly, the scene analysis is a location sensing technique, which uses features of a scene observed to determine the location of the objects in the scene. Secondly, the proximity method [8] determines object's location when the object is near a reference node. Thirdly, the triangulation location sensing techniques calculates the object's position by geometric properties of triangles [8][10]. It determines 2-D position using lateration requires distance measurements between the object and at least three non-collinear points. Basically, the IPSs always uses above techniques individually or in combination. To estimate the mobile position in WSN, the system needs to measure RSS values between object and known reference nodes. However, the RSS cannot be transformed to correctly distance. Frequency signals have transmission constraints in indoor environment that influences the accuracy of positioning systems. Normally, the IPSs affected by the RSS measurement errors. Moreover, the position of object cannot be calculated. Therefore, an algorithm which can determine correctly location of object with unreliable RSS is useful for establishing robust IPS.

This paper proposes a novel fuzzy logic approach to enhance to IPS estimation accuracy. Fuzzy logic is a fault tolerance design methodology which can be applied in developing both linear and non-linear systems. Hence, the proposed FLIPS method is able to estimate an object's position with distorted RSS.

II. Indoor Positioning Principles & Problems

This section presents the principle of basically position estimation algorithm which using RSS and describes the positioning problem formulation.

A. Received Signal Strength

The RSS based positioning approach estimates the position from samples of RSS vectors which can be obtained from wireless sensors hardware. The functionality should be worked at least three non-collinear fixed sensor points. RSS based IPSs are propagation-loss equations which measure RSS values to build signal strength map in a local area. The map can be generated using any method to measure the distance between RSS devices. Radio propagation model with positioning algorithm is always used to determine the object's position according to the RSS map [9]. Typically, The RSS values are within the interval [-40 dBm, -95 dBm] [11]. The industry standard always defines RSS value by 256 intervals.

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B. Geometric Mathematical Algorithm

The relation structure diagram of undetermined object and wireless sensors is shown in Figure 1. The object's coordinate which can be estimate is defined to (x_O, y_O). A, B, and C are wireless sensors and their coordinates are, (x_A, y_A), (x_B, y_B), and (x_C, y_C). The r_A, r_B, and r_C are the distance between object and sensors.

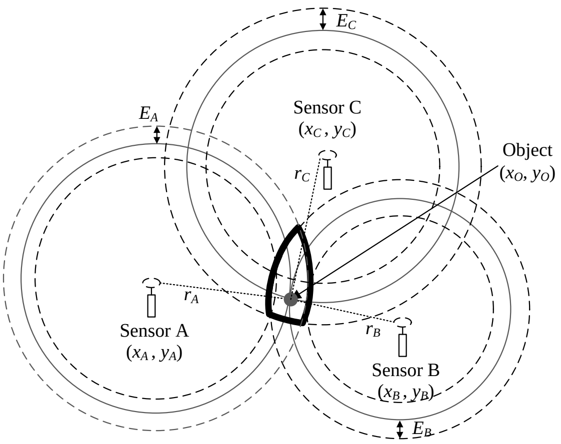

Fig. 1. The relation structure diagram of unknown object and wireless sensors.

The geometric triangulation mathematical model can be applied to find the object's coordinate (x_O, y_O). The general Euclidean distance (r_A, r_B, r_C) solutions can be calculated by the following equations.

$$
\begin{aligned}
r_A &= \sqrt{(x_A - x_O)^2 + (y_A - y_O)^2} \\
r_B &= \sqrt{(x_B - x_O)^2 + (y_B - y_O)^2} \\
r_C &= \sqrt{(x_C - x_O)^2 + (y_C - y_O)^2}\ ,
\end{aligned}
$$

then

$$
\begin{aligned}
(r_A)^2 - (r_B)^2 &= -2x_A x_O - 2y_A y_O - x_B{}^2 - y_B{}^2 \\
&\quad + 2x_B x_O + 2y_B y_O + x_A{}^2 + y_A{}^2 \\
(r_A)^2 - (r_C)^2 &= -2x_A x_O - 2y_A y_O - x_C{}^2 - y_C{}^2 \\
&\quad + 2x_C x_O + 2y_C y_O + x_A{}^2 + y_A{}^2\ .
\end{aligned} \tag{1}
$$

From the (1) to obtain

$$
\begin{bmatrix} (r_A)^2 - (r_B)^2 + \left(x_B{}^2 + y_B{}^2 - x_A{}^2 - y_A{}^2\right) \\ (r_A)^2 - (r_C)^2 + \left(x_C{}^2 + y_C{}^2 - x_A{}^2 - y_A{}^2\right) \end{bmatrix} = \begin{bmatrix} 2(x_B - x_A) & 2(y_B - y_A) \\ 2(x_C - x_A) & 2(y_C - y_A) \end{bmatrix} \begin{bmatrix} x_O \\ y_O \end{bmatrix}. \tag{2}
$$

Equation (2) can be used to extend for N pieces of sensor targets as

$$
\begin{bmatrix} (r_1)^2 - (r_2)^2 + \left(x_2{}^2 + y_2{}^2 - x_1{}^2 - y_1{}^2\right) \\ (r_1)^2 - (r_3)^2 + \left(x_3{}^2 + y_3{}^2 - x_1{}^2 - y_1{}^2\right) \\ \vdots \\ (r_1)^2 - (r_N)^2 + \left(x_N{}^2 + y_N{}^2 - x_1{}^2 - y_1{}^2\right) \end{bmatrix} = \begin{bmatrix} 2(x_2 - x_1) & 2(y_2 - y_1) \\ 2(x_3 - x_1) & 2(y_3 - y_1) \\ \vdots & \vdots \\ 2(x_N - x_1) & 2(y_N - y_1) \end{bmatrix} \begin{bmatrix} x_O \\ y_O \end{bmatrix}, \tag{3}
$$

define

$$
\overline{\mathrm{A}} = \begin{bmatrix} 2(x_2 - x_1) & 2(y_2 - y_1) \\ 2(x_3 - x_1) & 2(y_3 - y_1) \\ \vdots & \vdots \\ 2(x_N - x_1) & 2(y_N - y_1) \end{bmatrix}
\quad
\overline{\mathrm{B}} = \begin{bmatrix} (r_1)^2 - (r_2)^2 + \left(x_2{}^2 + y_2{}^2 - x_1{}^2 - y_1{}^2\right) \\ (r_1)^2 - (r_3)^2 + \left(x_3{}^2 + y_3{}^2 - x_1{}^2 - y_1{}^2\right) \\ \vdots \\ (r_1)^2 - (r_N)^2 + \left(x_N{}^2 + y_N{}^2 - x_1{}^2 - y_1{}^2\right) \end{bmatrix}. \tag{4}
$$

Hence, the object's coordinates are concluded as

$$
\begin{bmatrix} x_O \\ y_O \end{bmatrix} = \left(\overline{\mathrm{A}}^{\mathrm{T}} \overline{\mathrm{A}}\right)^{-1} * \left(\overline{\mathrm{A}}^{\mathrm{T}} \overline{\mathrm{B}}\right) \tag{5}
$$

Finally, solve (5), the object's coordinate (x_O, y_O) can be obtained.

III. PROBLEM STATEMENTS

As mentioned above, geometric mathematical method is usually effective in determining the coordinate of unknown object. However, the radio frequency based positioning has limitations in real environment, such as multi-path, diffraction, and reflection etc. Generally, the environment effects within buildings are strongly influenced by the structure of the building and the wall material used. Those effects will cause fault RSS measurement. It raises the challenge in designing an IPS. According to uncertain RSS, the mentioned positioning techniques cannot accurately determine the position of object.

IV. FUZZY LOGIC INDOOR POSITIONING SYSTEM DESIGN APPROACH

Fuzzy theory has been widely applied since Zadeh published the theory of fuzzy set in 1968 [12]. In this paper, the fuzzy theory is considered to design an indoor positioning system (FLIPS) for determining an object's position as shown in Fig. 2.

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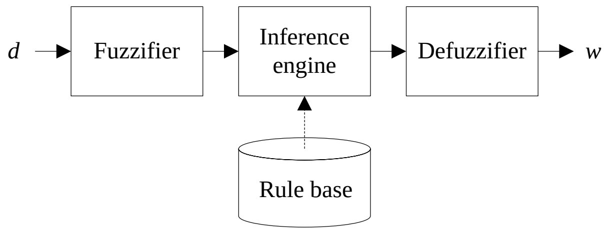

Fig. 2. Fuzzy logic system

In the proposed FLIPS, the weight of coordinate of each sensor will be determined by the fuzzy logic system. The fuzzy mechanism is described as follows:

Fuzzifier: triangular membership function.
Inference engine: madmani max-min.
Defuzzifier: height method.

In Fig. 2, the fuzzy input d is the distance between object and sensors. The crisp output variable (fuzzy singleton) using for the weight of the each sensor is denoted by w. The membership function and fuzzy singleton are shown in Figure 3. The values of the membership functions vary from 0 to 1. The linguistic variables are divided into five fuzzy subsets as follows: VS means very small, S means small, M means medium, L means large and VL means very large. The designed FLIPS estimate the object's location according to distance the object with sensors. Thus, use fuzzy output of all sensors to calculate the coordinate (x_e , y_e) of the object by equation (6) and (7).

$$x_e = \frac{x_1 \cdot w_1 + \cdots + x_N \cdot w_N}{\sum_{i=1}^{N} w_i} \tag{6}$$

$$y_e = \frac{y_1 \cdot w_1 + \cdots + y_N \cdot w_N}{\sum_{i=1}^{N} w_i} \tag{7}$$

where N is the number of sensors.

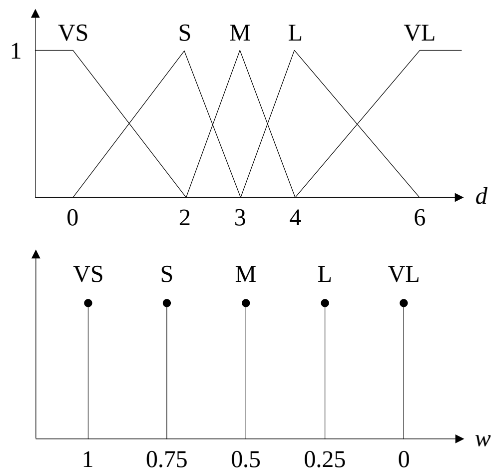

Fig. 3. Membership functions of fuzzy system.

V. Experimental Result

To evaluate the performance of proposed system, this section presents the experimental results of the indoor positioning system based on the proposed FLIPS. The platform used in this study is a ZigBee/IEEE 802.15.4 development module [11]. This module includes an 8-bit CPU core which is an enhanced version of the industry standard 8051 core. The test region is deployed using four ZigBee wireless sensors and one estimated object device in the indoor environment. For testing the performance of proposed system, 196 data (features) were measured within an interval of 0.4 meter in an area of 6 square meters (m^2) as shown in Figure 4. Each feature is a RSS vector R_i = [r_1 , r_2 , r_3 , ... r_N] that measured from each of the N base stations with wireless single receiver. In this study, N is defined as 4.

The distribution of triangulation method estimates result as show in Fig. 5. As the results shown, the triangulation method calculated result is imprecise, and some coordinates of result are outside the test area. Figure 5 shows the distribution of the proposed FLIPS estimated results. It demonstrates that the error of fuzzy logic method evaluating result is less than the triangulation method. Moreover, all coordinates of result nodes are inside the test area. The simulation results are summarized in Table 1. It describes the estimation error and stander deviation for comparing the performance between triangulation method and the proposed FLIPS. Table 1 describes the fuzzy logic method is valid for IPS problem. Besides, FLIPS provides better performance and more stable estimation than triangulation method.

TABLE I. THE ESTIMATION RESULTS COMPARISON OF TRIANGULATION AND FUZZY METHOD.

unit (m)	Triangulation	Fuzzy Logic
Absolute Mean Error	1.692095	1.188623
Stander Deviation	0.911634	0.621071

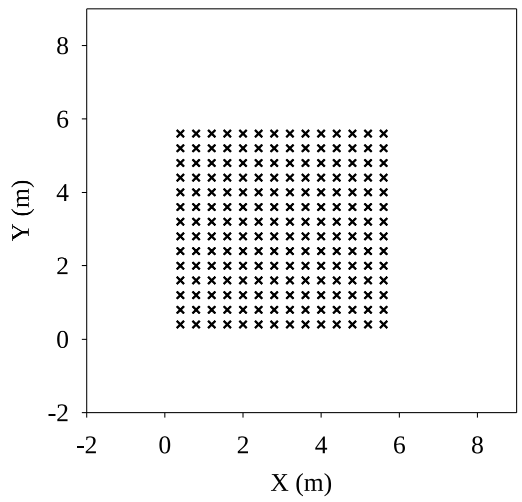

Fig. 4. Distribution of 196 test nodes

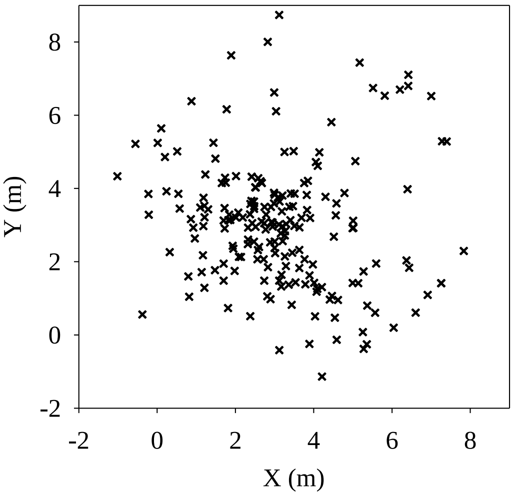

Figure 5. Distribution of triangulation method estimates result.

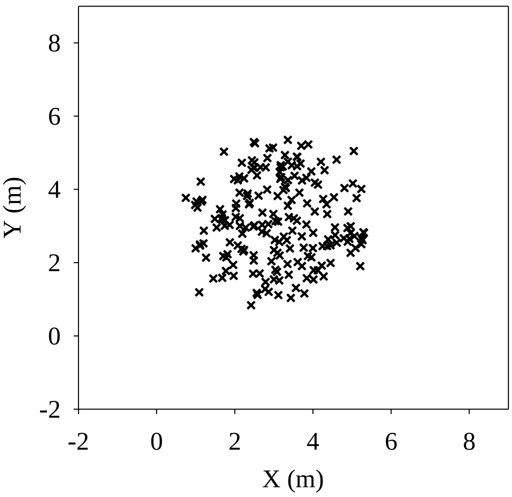

Figure 6. Distribution of fuzzy logic method estimates result.

VI. CONCLUSIONS AND FUTURE WORK

In the indoor environment, the RSS based positioning techniques estimates imprecision result by interference from multi-path, diffraction and reflection effects. Therefore, this paper proposed a new FLIPS to determine the location of object when the measured distance were distorted. The demonstrate shows that the fuzzy logic inference performed better than triangulation method. Besides, the determination results of FLIPS are more stable. The proposed approach is advanced to establish as hardware or embedded system, duo to its low complexity. The future studies will put more emphasis on RSS propagation-loss equations for measuring more accuracy distance between the wireless devices.

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