Indoor Positioning System Based on Rotatable Directional APs

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***Abstract*—Traditional indoor positioning systems encounter many practical problems, which lead to coarse positioning accuracy and high requirements of human efforts. In this paper, we propose a new positioning system. Only two directional access point (AP) are employed and distributed in the indoor environment, and mobile device such as cell phone receives the signal strength from both APs and send the data to the server. Then, the location of the phone can be calculated. Compare with previous works, our system is simple, low-cost, far away from obstacles interference, and don't need to collect large amounts of data. It is suitable for emergency situations and high dynamic wireless local area network (WLAN) environment. Experiment results show that the positioning accuracy is improved much, up to 92.9% and the positioning error has been reduced to 2.133 meter.**

***Keywords*—Indoor Positioning; Directional AP; Emergency; Wi-Fi Signal; Dynamic WLAN Environment**

I. Introduction

In many emergency indoor scenarios and high dynamic WLAN environment, such as fire site, specifically, when APs of site are invalid. It requires a tracking system, which is easy-to-setup, relatively safe and convenient to use. At present, there are a plenty of localization methods and systems, but in this particular situation, those positioning systems have their limitations. Such as GPS [1], it is not available for indoor case for it needs to maintain visible distance with satellite. Mobile base station location [2], its location accuracy depends on the distribution density of base station tower. Infrared positioning [3], Ultrasonic positioning [4], Bluetooth [5], these three positioning technologies are easily influenced by the obstacles in the environment, and still need additional hardware facilities. In addition, Bluetooth localization way can only detect the objects in short distances. At last, there are two ways for localization in Wi-Fi positioning system. One is based on the propagation model [6], but this method is easily influenced by the environment. The other way is machine learning technique [7], and this method consists of two phases, offline training and online testing, users need to gather a lot of data in whole phase.

Since there are so many shortages for the traditional indoor positioning systems, we propose a new system to handle those problems. It is based on rotatable directional APs, and the positioning problem is transformed into a trigonometric problem. The advantages of our system as follows: Firstly, it is easy-to-setup and can be built in anywhere and anytime. Secondly, it is low cost, and we can deploy this system with common equipments rather than costly facilities. Thirdly, the environment factor such as time, temperature, humidity, obstacles will not affect localization accuracy, and we also don't need to rely on the existing APs of environment, so it can be applied to high dynamic WLAN environment. Furthermore, the most important thing is that it avoids large scale data collection work and can quickly find the location of the mobile device. Experimental results have proved positioning precision of the new indoor positioning system.

The rest of the paper is organized as follows: the second section introduces the system structure, and the third section describes the system theory. The fourth section elaborates the experiment results, and the fifth section is conclusion and prospect.

II. System Structure

Figure 1 shows the structure of the system: two rotatable directional APs, a server and a mobile device. Conventional Wi-Fi AP fixes on rotatable directional antenna to form the rotatable directional AP, which sends signals to the mobile device. The server is a common computer running our background processing program. Mobile device must have communication function, and server, directional APs together should keep communication unblocked.

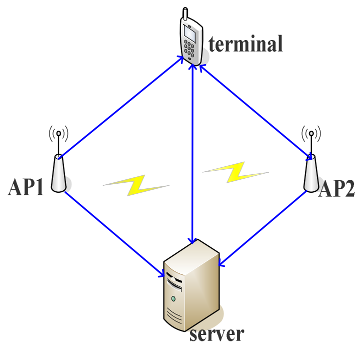

Fig.1. System architecture

The whole application process as show in Fig.2, two rotatable directional APs are placed on both sides of positioning area, turning round and launching signal uninterrupted. The mobile device moves in this area, receiving two directional APs' signal, and then returning data to the server, analyzing those data by server. Thus we can obtain angle relationship between the mobile device and the two APs, and calculate mobile device's location based on the angle relation.

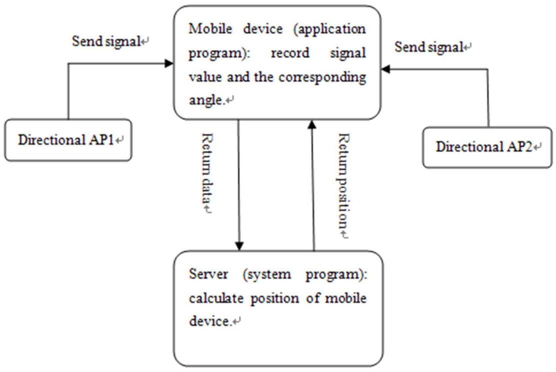

Fig.2. System flowchart

III. SYSTEM PRINCIPLES

A. System Feature

The feature of our system is using rotatable directional AP. We use rotation to get angle information, but why choosing two directional APs? We illustrate it with a picture (in Fig.3). A, C use single AP, the blue part is estimation area, figure C has better effect than A, because figure C uses directional AP while figure A uses omni-directional AP. For directional characteristic, strong signal only can be launched toward a certain fan-shaped area. B, D use double APs, candidate area of position estimate is blue superposition part. As the beam width angle of directional AP is in proportion to strong signal strength area. So if the beam width angle is enough small, the fan-shaped area will narrow subsequently, and superimposed area will also reduce. Therefore, the blue quadrilateral region is that we want to know.

To simplify this issue further, in this paper, we take angle bisector of each fan-shaped area, and line of two APs' connection direction to constitute a triangle. Our positioning problem is transformed a triangle function problem, we know two angles and a side, what we need to do next that ask the third point coordinates.

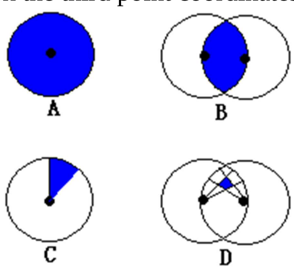

Fig.3. System feature

B. Communication Module

The whole implementation process involves two modules. The first one is communication module. Two directional APs rotate and send signal to the mobile device constantly at the same time. The mobile device record those received signal strength and the corresponding angle information .We can get that angle information according to the time and AP's rotating speed and cycle. Of course the rotary tables must be uniform, then, we also need to set zero graduation. In this paper, we put two APs' connection direction as zero graduation direction.

Then, the mobile device transmits all data to the server. As shown in Fig.4 (location of AP and mobile device are unchanged, but AP's direction in change), there is the simulation result. The x-coordinate denotes collecting times, y-coordinate represents signal strength value. Red line is static directional AP with facing the mobile device, signal strength stable basically. While blue line shows the rotating directional AP, when the signal strength are situated in the peaks, just also directional AP rotates to facing the mobile device's direction. So no matter how many are the signal strength value, server will extract corresponding angle of the biggest signal strength value of each cycle. Thus the influence of environment in signal intensity is not related with positioning accuracy.

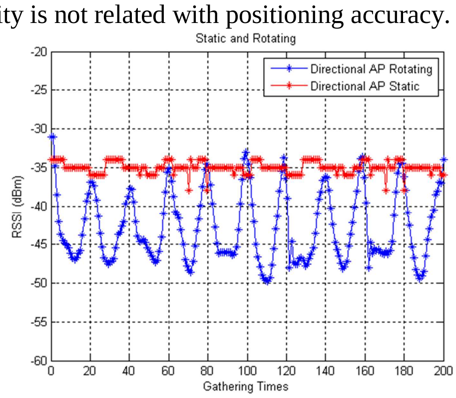

Fig.4. Signal strength fluctuation

In addition, along with rotation of directional AP, we also see a slight periodic and regular change of signal intensity (in Fig.4). Thus in order to make rule more obvious and obtain more accurate angle information, we can collect more cycles in the same place, and then make an adjustment of direction properly and timely. Result of simulating after adjusting is similar to cosine curve (in Fig.5). The upper graph is raw data, the following cosine curve is formed after adjusting .Thus, according to the periodic law of cosine curve, we want to know that the angle of corresponding peaks position.

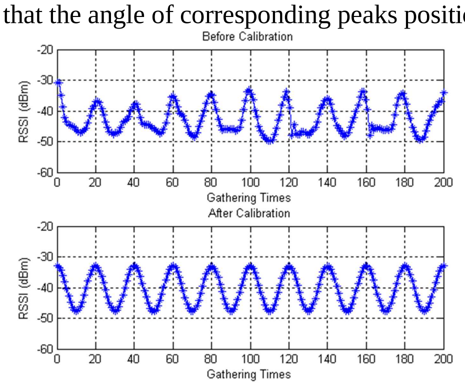

Fig.5. Before calibration and after calibration

C. Background Processing Module

The other one is the background processing module, as show in Fig.6. Our positioning problem is transformed into a trigonometric problem, (x1, y1) ,(x2, y2) place two rotating directional APs, blue area is the signal radiation district, superposition part of two blue regions is estimate area, namely the square area ABCD. In this experiment, we take angle bisector of each blue area, and line of two APs' connection direction to constitute a triangle. So the angles we want to know that are marked as angle α and angle β, and (x, y) is the position we want to ask. But for signal strength does not change significantly in the square area ABCD. So these angles will have a range of error ±5 (For we use the directional antenna with small beam width angle (level 10 °), it is in proportion to strong signal strength area. That is to say, beam width angle is equal to radiation angle), positioning accuracy may also be affected more or less. But after test and analysis, the degree of influence is very light.

The first module has introduced the process of obtaining the two angles, while we can measure m directly. Finally, according to relations of the trigonometric function, we can calculate (x, y).

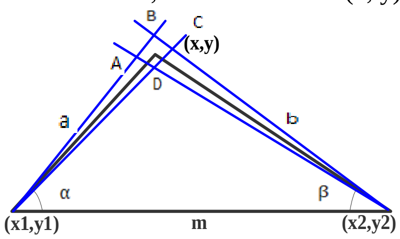

Fig.6. Two APs and mobile device component triangle

Computational process as follows, known edge m, angles α and β, consider another two edges as a, b, according to (1) and (2):

$$\begin{cases} \cos\alpha = (a^2 + m^2 - b^2)/2am & (1) \\ \dfrac{a}{\sin\beta} = \dfrac{b}{\sin\alpha} & (2) \end{cases}$$

We discuss in both cases, first, while α = β, we can work out a, b by (3) and (4):

$$\begin{cases} a = \dfrac{m}{2 \times \cos\alpha} \quad (0 < \alpha, \beta < \pi) & (3) \\ b = a = \dfrac{m}{2 \times \cos\alpha} \quad (0 < \alpha, \beta < \pi) & (4) \end{cases}$$

The second α and β is unequal, we may calculate by means of (5) and (6):

$$\begin{cases} a = \dfrac{m \times \cos\alpha - \dfrac{m \times \sin\alpha}{\sin\beta} \times |\cos\beta|}{1 - \dfrac{\sin^2\alpha}{\sin^2\beta}} (0 < \alpha, \beta < \pi) & (5) \\ b = a \times \dfrac{\sin\alpha}{\sin\beta} \quad (0 < \alpha, \beta < \pi) & (6) \end{cases}$$

Then assume (x1, y1) coordinates (0, 0), (x2, y2) coordinates (m, 0). According to the followings (7) and (8):

$$\begin{cases} \sqrt{(x - x_1)^2 + (y - y_1)^2} = a & (7) \\ \sqrt{(x - x_2)^2 + (y - y_2)^2} = b & (8) \end{cases}$$

We can ask out (x, y) coordinates.

$$\begin{cases} x = \dfrac{a^2 + m^2 - b^2}{2 \times m} & (9) \\ y = \sqrt{a^2 - x^2} & (10) \end{cases}$$

IV. Experiment And Analysis

A. *Experimental Environment*

The experiment is carried out in laboratory with an area of about 15m*24m, there are many cabinet and pillars in this room (in Fig.7). The gain of the directional AP (in Fig.8) is 24 DBI, the horizontal and vertical beam width angle is 10 degree and 14 degree respectively, and rotating speed is 5 degree per second, the cycle is 180 degree. We deploy two directional APs on the two sides of this room and the distance between them is 10 meters. Then we may move in the room with taking mobile device, the server will track the position of mobile device, and return the position results to the user.

Fig.7. Simple scene graph of test

Fig.8. Rotating directional AP

B. *Performance of Test Equipment*

For directional APs launch and receive strong signals in a certain fan-shaped area, whereas the signal is very weak in the other direction. We made a set of experiments to verify this characteristic, directional AP's position and direction as shown in Fig.9, it launches signal in the motionless turntable. We can clearly notice that the district facing the directional AP have strong signal strength (red marked area), the bigger offset of the directional AP, the weaker signal strength is detected (blue marked area). The beam width angle of directional AP is in proportion to strong signal strength area. In other words, smaller beam width angle correspond to narrower strong signal strength area, beam width angle is equal to radiation angle.

But we can also see obviously, though we use the directional antenna, there are still some unstable data. If we use our new method, could bypass these error data and execute more accurate positioning.

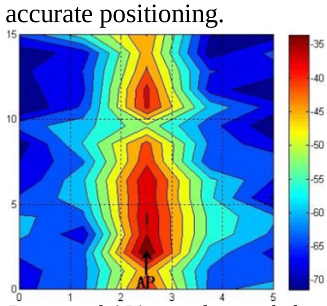

Fig.9. Directional AP's signal strength distribution

C. The Analysis of Experimental Results

In our experiment, only angles affect positioning accuracy, and there are two reasons will lead to angle error. First, the beam width angle of directional AP (level 10 °) , as we use two same directional APs, so angle α and angle β （in Fig.6）have a range of error ±5° respectively. Then, communication process can cause delay with 1 to 2 seconds, for we record angle information according to the time and AP's rotating speed and cycle in communication module, and the rotating speed of directional AP is 5 degree per second, so it may lead to error of 5 degree. Therefore, angle α and angle β all would have a range of error ±10° .

For any estimated point, we may analyze positioning error based on formula (9) and (10). Such as table 1 below shows the result of error analysis of a point. The first column lists some cases of possible angle deviation, the front number is the error of α, and the latter is the error of β. The second column displays coordinates of mobile device under the deviations. The third column is positioning error compared with real coordinates. While angle deviation is (0° , 0°), corresponding one is true coordinates (real measured value) .We can notice the biggest positioning error is 2.133 m.

Angle deviation	(x , y) (m)	Positioning error (m)
(0° , 0°)	(5.868, 4.920)	0
(0° , +5°)	(6.298, 5.281)	0.562
(0° , -5°)	(5.437, 4.559)	0.562
(+5° , 0°)	(5.437, 5.433)	0.670
(-5° , 0°)	(6.298, 4.407)	0.670
(+5° , -5°)	(5.001, 4.996)	0.871
(-5° , +5°)	(6.709, 4.695)	0.871
(0° , +10°)	(6.735, 5.648)	1.132
(+10° , 0°)	(5.001, 5.953)	1.350
(+10° , +5°)	(5.451, 6.490)	1.625
(-10° , +10°)	(7.499, 4.327)	1.735
(+10° , +10°)	(5.923, 7.053)	2.133

Table 1. Positioning error estimation

To verify the feasibility of our method, experiment of tracking mobile device is taken. At first we measure real position of 322 points in laboratory, and then use our positioning system to track those points, getting a series of estimated position. Compare with real coordinates, we can draw positioning error, its cumulative distribution function as shown in Fig.10.We can note that our method gets an accuracy of 92.9% and the biggest positioning error is 2.133 m.

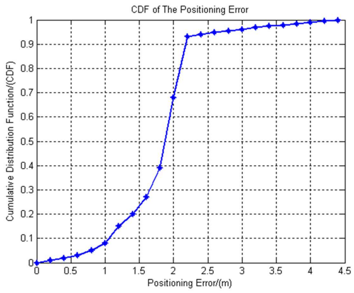

Fig.10. CDF of the positioning error

V. CONCLUSION AND OUTLOOK

Based on two rotatable directional APs, our indoor locating system transforms the positioning problem into a triangle function problem. It can not only overcomes the high system cost, complex deployment, the poor quality scalability, but also accurately estimate the position of the mobile device without collecting large amounts of data, and the biggest positioning error has been achieved 2.133 m with an accuracy of 92.9%.

Due to rotating speed is 5 degree per second, and cycle is 180 degree, making the time of updating position reach 36 seconds, so we need to enhance it by increasing rotating speed. Additional, we may still improve the localization accuracy further by obtaining more accurate angle information. These all depend on looking for more sophisticated rotating equipment. Consequently, it makes the system more suitable for the high dynamic indoor wireless environment.

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