# Indoor Passive Ranging Based on WiFi

Jiazhi Dong, Yuwen Wang
*Department of Aeronautics and Astronautics*
*University of Electronic Science and Technology*
*Chengdu, Sichuan Province, China*
*{uestcdjz@sina, wangyw@uestc.edu}.cn*

Xiaofu Shang, Zhili Wang
*Department of Aeronautics and Astronautics*
*University of Electronic Science and Technology*
*Chengdu, Sichuan Province, China*
*{shangxiaof, gnaw014}@163.cn*

***Abstract* - In this paper, we briefly analyzed the advantages of passive distance measurement based on Wireless Fidelity (WiFi). Based on the analysis of the principle of traditional interferometer direction finding, we derived the equations which are suitable for indoor distance measurement. Through theoretical analysis and simulation, we prove the correctness of the equations. Finally, we analyze and conclude the conditions of using the method, the scope of distance measurement, and the main influencing parameters of system accuracy.**

**Index Terms - indoor ranging, passive ranging, WiFi, interferometer**

## I. INTRODUCTION

WiFi, which is known as the 802.11b standard, is a wireless network communication industry standard defined by the IEEE, it uses a frequency band at 2.4GHz [1]. The communication distance of WiFi is 305m in an open area, which is 76m to 122m in a closed area.

With the development of information technology, WiFi technology is widely used in various industries and places. At present, most of WiFi-based indoor positioning technology use active positioning, which can be divided into three categories: 1. positioning based on infrastructure, such as in [2], It need to establish wireless mapping foundation, while requiring complex work and high investment to construct this environment; 2. positioning based on the signal transmission model, as in [3] [4] [5], even out of the hardware infrastructure bondage to some extent, it is very difficult to create an effective signal transmission model; 3. positioning based on signal strength, as in [6] [7], even out of the shackles of hardware, the establishment of the database requires a lot of time, and the adaptability to environmental change is weak. What's more, many scholars have focused on hybrid location systems combining two or more techniques in order to improve the accuracy and precision of the location estimation [8] [9] [10]. Considering the particularity of the indoor environment, compared with the active positioning technology, the probe system passive using the passive location technology do not radiate electromagnetic waves, with a strong ability to hide. So it has important significance for enhancing the system viability and ability to work in a complex electromagnetic environment, it can be used to detect intruders in the home or any other area of particular security interest [11] [12], and to help emergency responders, military forces, or police arriving at a scene where entry into a building is potentially dangerous[13] [14], et. The most important thing is that it is easy and cheap to locate based on WiFi. But so far, there are few studies on indoor passive location based on WiFi.

The distance from interferometer to the target position is often tens or hundreds of kilometers in the traditional technique. In [15] [16] [17], considering that the radiated signal enters two receivers in parallel. In this paper, the indoor distance is very short (generally less than 20m), so the signal is not considered to the receiver in parallel.

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## II.THE METHOD OF RESEARCH

We know when the phases of signal arriving two receivers are simultaneous detected, you can achieve the purpose of direction-finding (DF) with the technology of one-dimension single baseline interferometer. In [18] [19], they adopt the direction-finding crossing to locate, but the more the angle is used, the greater the probability of error is made. In this paper, system structure diagram is showed in Fig. 1. General process for the system working as follows: when a person uses the mobile terminal with WiFi function and opens WIFI, it will automatically send probe frame at the same time, this kind of signal will be received by the radio DF antenna, after the signal be converted to electrical signals and though preprocessing, it will be transmitted to the receiver, then the system will analyze the signal to get the useful information needed by DF and ranging, the exact location of the target radiation could be calculated with the relevant algorithm at last.

In Fig. 1, the antennas A, B, C are collinear, the distance between WiFi radiation source O and antennas A, C, B are $R_1, R_0, R_2$, the phase difference between A and C, B and C are $\varphi_1, \varphi_2$, the distance between the antenna A and C is $L_1$, the distance between the antenna B and C is $L_2$. Establishing the coordinate system is showed in Fig. 1, the angle between OC and the y-axis direction is $\alpha$, the azimuth $\alpha$ is positive when the direction from the y-axis direction to the x-axis direction.

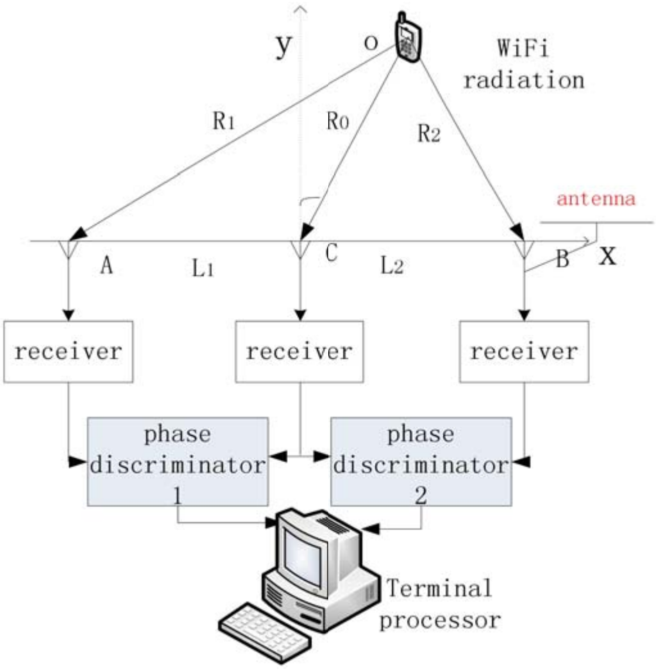


Fig. 1 system structure diagram

Let $R_1 = R_0 + r_1$, $R_2 = R_0 + r_2$, $L_1 = L_2 = L$, we can easily obtain the following formula:

$$R_0 = \frac{2L^2 - \frac{(r_1+r_2)^2}{2}}{2(r_1+r_2)} + \frac{2L^2 - \frac{(r_1-r_2)^2}{2}}{2(r_1+r_2)}$$

$$= \frac{2L^2 - \frac{(r_1-r_2)^2}{2}}{2(r_1+r_2)} + \frac{L^2}{r_1+r_2} - \frac{r_1+r_2}{4} \qquad (1)$$

$$r_1 - r_2 = \frac{4R_0 \cdot L\sin\alpha}{R_1+R_2} \qquad (2)$$

In this paper, the wavelength of radiation source WiFi $\lambda$ =c/f=0.125m, in order to improve the measurement accuracy, let $L = 0.5\,m > 0.5 \cdot \lambda$ . It is impossible to make $R_0 >> L$ , because the indoor distance is very short, so the value of $\frac{L^2}{r_1+r_2}$ is small. Through the triangular relationship, we can easy to get $|r_1+r_2| \le |r_1 - r_2|$, when the $\varphi \neq 0$ .

Therefore (1) can be simplified as:

$$R_0 \approx \frac{2L^2 - \frac{(r_1-r_2)^2}{2}}{2(r_1+r_2)} \qquad (3)$$

From (2), we can get:

$$r_1 - r_2 \approx 2L\sin\alpha \qquad (4)$$

Replacing (4) into (3), we can obtain:

$$R_0 = \frac{L^2\cos^2\alpha}{r_1+r_2} \qquad (5)$$

$$\text{Let} \begin{cases} r_1 = k_1\lambda + \frac{\varphi_1}{2\pi}\lambda \\ r_2 = k_2\lambda + \frac{\varphi_2}{2\pi}\lambda \end{cases} \qquad (6)$$

In (6), $k_1, k_2$ are integers, which have the same positive and negative with $\varphi_1, \varphi_2$, $\varphi_1, \varphi_2 \in (-\pi, \pi)$. From (5), we can get:

$$r_1 + r_2 = \frac{L^2\cos^2\alpha}{R_0} \le \frac{L^2}{R_0} \qquad (7)$$

From (6), we can get:

$$r_1 + r_2 = (k_1 + k_2)\lambda + \left(\frac{\varphi_1}{2\pi} + \frac{\varphi_2}{2\pi}\right)\lambda \qquad (8)$$

$$\text{When } R_0 > \frac{L^2}{\lambda} = \frac{0.5^2}{0.125}\,m = 2.0\,m, \qquad (9)$$

combined with (7)(8), we can obtain:

(1).when $0 \le \varphi_1 + \varphi_2 < 2\pi$ , we can get $k_1 + k_2 = 0$

$$r_1 + r_2 = \frac{(\varphi_1 + \varphi_2)\lambda}{2\pi} \qquad (10)$$

when $-2\pi < \varphi_1 + \varphi_2 < 0$ , we can get $k_1 + k_2 = 1$ ,

$$r_1 + r_2 = \frac{(2\pi + \varphi_1 + \varphi_2)\lambda}{2\pi} \qquad (11)$$

From (5), (9), (10)we can get :

when $0 < \varphi_1 + \varphi_2 < 2\pi$ ,

$$R_0 = \frac{2\pi L^2\cos^2\alpha}{(\varphi_1 + \varphi_2)\lambda} \qquad (12)$$

when $-2\pi < \varphi_1 + \varphi_2 < 0$ ,

$$R_0 = \frac{2\pi L^2\cos^2\alpha}{(2\pi + \varphi_1 + \varphi_2)\lambda} \qquad (13)$$

From (12), (13), we can easily know: after measuring the azimuth $\alpha$ , the phase difference $\varphi_1, \varphi_2$ can be measured by the long baseline phase interferometer, so we can calculate the distance of WiFi radiation source.

## III. PERFORMANCE ANALYSIS

Since this article is assumed that the system azimuth has been gotten by one-dimension single baseline interferometer, therefore, we only need to prove the accuracy of distance measurement formula. Now assuming that the error of system azimuth is zero, phase measurement error is $1^0$ .Assuming that the true distance of the target is R, the actual measured distance of the target is $R_0$ , the relative error is $\nabla = \frac{|R_0 - R|}{R} \cdot 100\%$ . Combined with (5), (12), we can get the relation between $\nabla$ and the distance of x-axis direction, which is showed in Fig. 2. The abscissa represents the horizontal distance of x-axis direction, the range of simulation is (2m, 10m) in x-axis direction, and the vertical axis represents the relative error. Easily obtaining from Fig. 2:with the increase of azimuth $\alpha$ , the relative error $\nabla$ increases at the same time; with the increase of the horizontal distance x, the relative error $\nabla$ decreases at the same time; when the azimuth $\alpha \le 30^0$ , the relative error $\nabla$ is almost zero; when the horizontal coordinate x > 5m, the relative error is small, when x> 6m, the relative error is less than 1, the size of azimuth has little effect on the measured values at this time.

When $\alpha = 30^0$ , the range of x-axis is 1.50 m to 5.50 m, the interval is 0.50m, the accuracy of the distance measured value is 0.01m, The contrast of the measured value and the true value is showed in Fig. 3.

When $\alpha = 80^0$ , the range of x-axis is 2.00 m to 8.50 m, the other parameters are the same as in the Fig. 3, the contrast of the measured value and the true value is showed in Fig. 4.

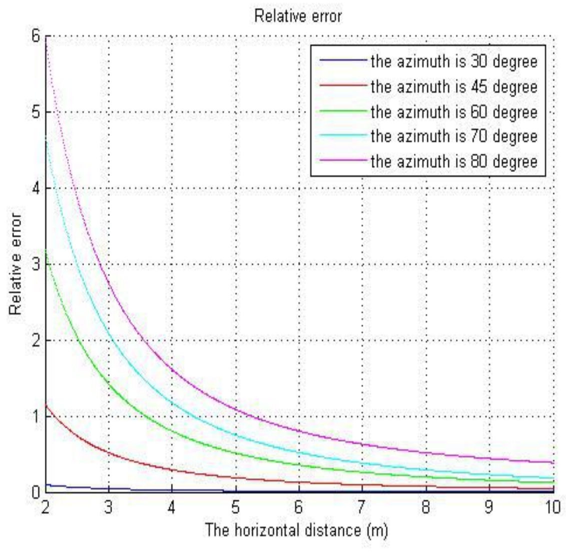


Fig. 2 The relationship between $\nabla$ and $\alpha$ , x

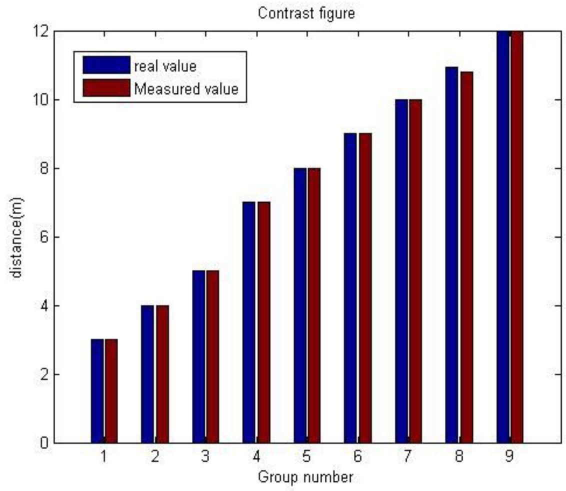


Fig. 3 $\alpha = 30^0$

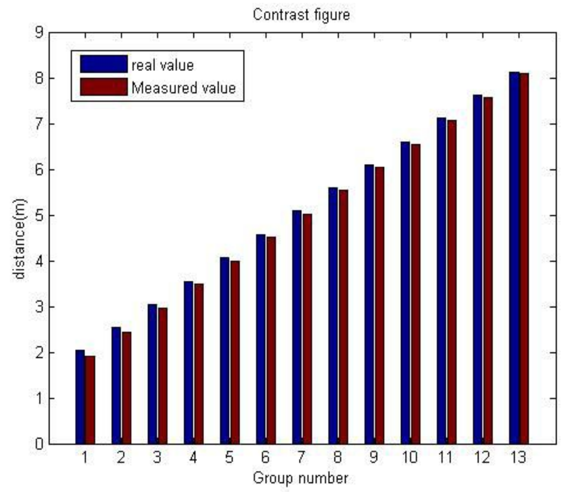


Fig. 4 $\alpha = 80^0$

Through the analysis and the contrast between Fig. 2, Fig. 3 and Fig. 4, we come to a conclusion: the smaller the azimuth angle, the smaller the distance measurement error. In this paper, assuming $\alpha \neq 0$ when (1) to (3), in order to demonstrate whether the formula (12) is right for all the azimuth $\alpha \in [0, \pi/2)$, let $\alpha = 0$, that is, all the measured points are in the y-axis direction, we choose the range from 2.50m to 11.00m. The other parameters are same as the Fig. 3. The contrast of the measured value and the true value is showed in Fig. 5. It is apparent that the distance measurement formula (11), (12) are right and their measurement errors are very small from Fig. 5 when the azimuth is zero.

Let $\varphi = \varphi_1 + \varphi_2$ , we can get:

$$R_0 = \frac{4\pi \cos^2 \alpha}{\varphi} (0 < \varphi < 2\pi) \qquad (14)$$

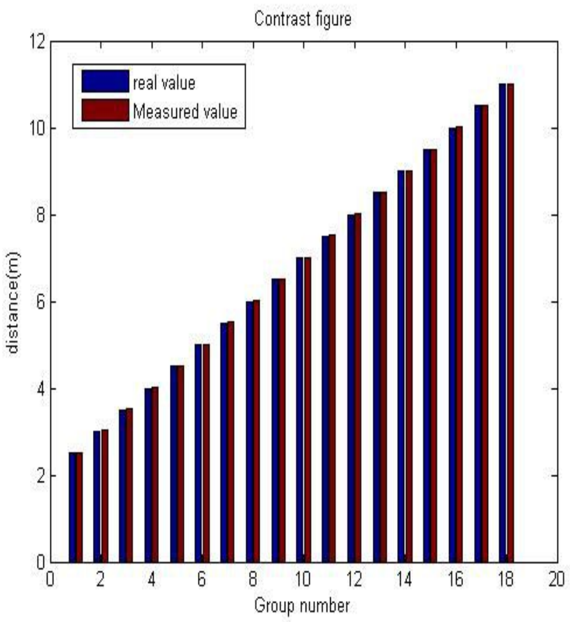


Fig. 5 $\alpha = 0^0$

$$R_0 = \frac{4\pi\cos^2\alpha}{2\pi+\varphi} \quad (-2\pi < \varphi < 0) \tag{15}$$

Simulating (14), (15), the relationship between $R_0$ and $\alpha, \varphi$ is showed in Fig. 6, the azimuth $\alpha \in [0, \pi/2)$, in Fig. 6.a , the sum of the phase difference $\varphi \in (0, 2\pi]$, in Fig. 6.b, the sum of the phase difference $\varphi \in [-2\pi, 0)$ .From the Fig. 6, we can roughly get: when the distance close to the interferometer, all the azimuth can be used to ranging.

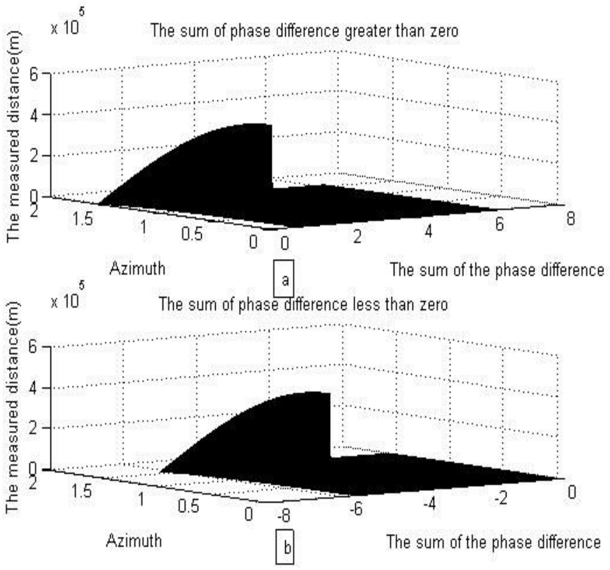


Fig. 6 $R_0 - \varphi - \alpha$

Let $t = \varphi / 2\pi$ , from (14), we can get:

$$t' = -\frac{2\cos^2\alpha}{R_0{}^2} \tag{16}$$

If the system required the distance resolution is d, the phase measurement accuracy of the system is $\sigma$ , combined with (16), we can easy to get the maximum detection range of the system:

$$R_{max} = \sqrt{\frac{2 \cdot d}{\sigma}} \cos\alpha \tag{17}$$

According to the relationship that giving different values of x, y, z, you can get different maximum distance measurement, we create a table, as Table I shows. By comparing the data in the table, we can draw the following conclusions: 1.the greater azimuth, the shorter the maximum distance precisely measured from the data of 3, 7, 8, 9, 10 lines; 2.the phase measurement accuracy has the largest impact on the system performance from the contrast data of 2 line with data of 3 line, data of 4 line with data of 6 line; 3.to ensure the applicability of the system and the high precision of ranging, azimuth should be less $60^0$ from all the data of table I.

TABLE I. the maximum measuring distance

| | $\alpha$ | d | $\sigma$ | $R_{max}$ |
|---|---|---|---|---|
| 1 | $0^0$ | 1m | 1/360 | 26.83m |
| 2 | $0^0$ | 0.1m | 1/360 | 8.49m |
| 3 | $0^0$ | 0.1m | 1/21600 | 65.73m |
| 4 | $30^0$ | 1m | 1/360 | 23.24m |
| 5 | $30^0$ | 0.1m | 1/360 | 6.00m |
| 6 | $30^0$ | 1m | 1/21600 | 179.99m |
| 7 | $30^0$ | 0.1m | 1/21600 | 56.92m |
| 8 | $60^0$ | 0.1m | 1/21600 | 32.86m |
| 9 | $70^0$ | 0.1m | 1/21600 | 22.48m |
| 10 | $80^0$ | 0.1m | 1/21600 | 11.41m |

## IV.CONCLUSION

This paper proposed a new method for indoor passive location based on WiFi. Considering the particularity distance measurement of WiFi-based indoor, we change the traditional phase interferometer measurement conditions, and derive the distance measurement formula for short distance under the premise of the azimuth which has been measured. Through simulation and theoretical derivation, the formulas have been proved accurately for ranging. When the azimuth is less than

$70^0$ and the phase measurement accuracy of the system is $1'$, we can ensure that the distance resolution is less than 0.1m. The key to realize WiFi-based passive ranging is to improve the phase measurement accuracy. Since the formula is derived under the condition that the distance from the WiFi radiation to antenna of ranging is greater than 2m, so if the distance is less than 2m, the proposed method of distance measurement is not effective.

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