

# Research on 3D Fingerprint Positioning Based on MIMO Base Station

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**Abstract.** The aim of this article is to solve the problem that the accuracy of traditional positioning algorithm decreases in complex environment and to provide some ideas for the few researches of fingerprint localization algorithm in three-dimensional space. This paper builds a system model in a three-dimensional space, provides three reference point distribution methods, and discusses the positioning performance under these distribution methods. After that, based on the high base station deployment density, multi-point fusion positioning method is used to locate the target, which further improves the positioning accuracy and makes more effective use of reference point resources. Finally, a backward-assisted positioning method is proposed, which uses the position information of the positioned points to assist the positioning of the current point. Research shows that this method can improve the positioning accuracy and has good versatility.<sup>2</sup>

**Keywords.** Three-dimensional, multi-point fusion positioning, backward-assisted positioning

## 1. Introduction

In recent years, location-based services have attracted widespread attention in various industries. Different from the traditional positioning algorithm, the fingerprint positioning algorithm uses some corresponding characteristics generated during the signal transmission to achieve positioning [1-3]. In the process of wireless signal transmission, due to the influence of multipath effects, the channel characteristics at different physical locations will reflect some unique characteristics, which called the fingerprints of the signal. When there is a positioning requirement, the fingerprint information of the point to be located is compared with the fingerprint information in the database, and the information of the point is estimated according to a certain similarity criterion. The flow chart of the fingerprint location algorithm is shown in Figure.1 [4-5].

The current fingerprint positioning algorithms mainly focus on the two-dimensional plane, and there are few researches on the positioning in the three-dimensional space. But in modern indoor scenes, especially in environments such as shopping malls, office buildings or hospitals, the positioning of the three-dimensional space becomes more

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important. Secondly, with the development of 5G, the combination of fingerprint location algorithms with new generation communication technologies and scenarios is still in progress. Therefore, the research in this article will focus on the above issues. The current fingerprint positioning algorithms mainly focus on the two-dimensional plane, and there are few researches on the positioning in the three-dimensional space. But in modern indoor scenes, especially in environments such as shopping malls, office buildings or hospitals, the positioning of the three-dimensional space becomes more important. Secondly, with the development of 5G, the combination of fingerprint location algorithms with new generation communication technologies and scenarios is still in progress. Therefore, the research in this article will focus on the above issues.

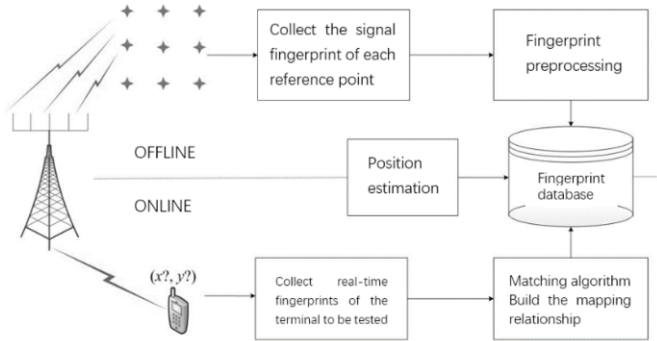


Figure 1. The flow chart of the fingerprint location algorithm.

## 2. Three-dimensional positioning based on massive MIMO

### 2.1. Three-dimensional space model

For most open areas outdoors, there is no special requirement for the height of the positioning point, thus in the positioning process, only two coordinate axes are often needed to determine the location. However, people currently spend most of their time in buildings. Although for some specific scenes, they can still be positioned only in the horizontal plane, for most scenes, an additional height coordinate is needed for accurate positioning. Therefore, in the three-dimensional space, the reference point distribution model and the scatterer model require an additional height coordinate axis compared to the two-dimensional space. The three-dimensional model of the scatterer is shown in Figure.2.

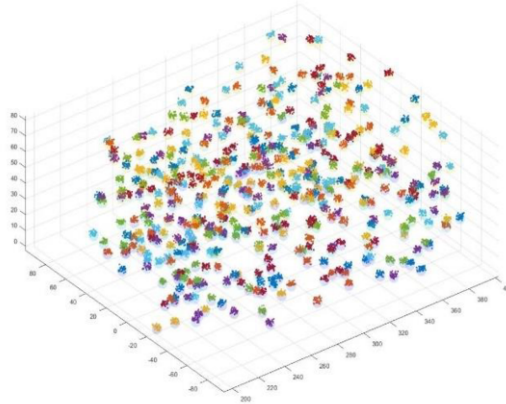
For the reference point distribution model in fingerprint positioning, in two-dimensional positioning, the reference points are uniformly distributed. However, considering that the scene in the three-dimensional space is more complicated, and because there is a height coordinate axis, when setting the reference point, it can be considered to introduce a small height float on the Z axis to better show the difference in fingerprint characteristics.

There are three types of reference point distribution models in this article:

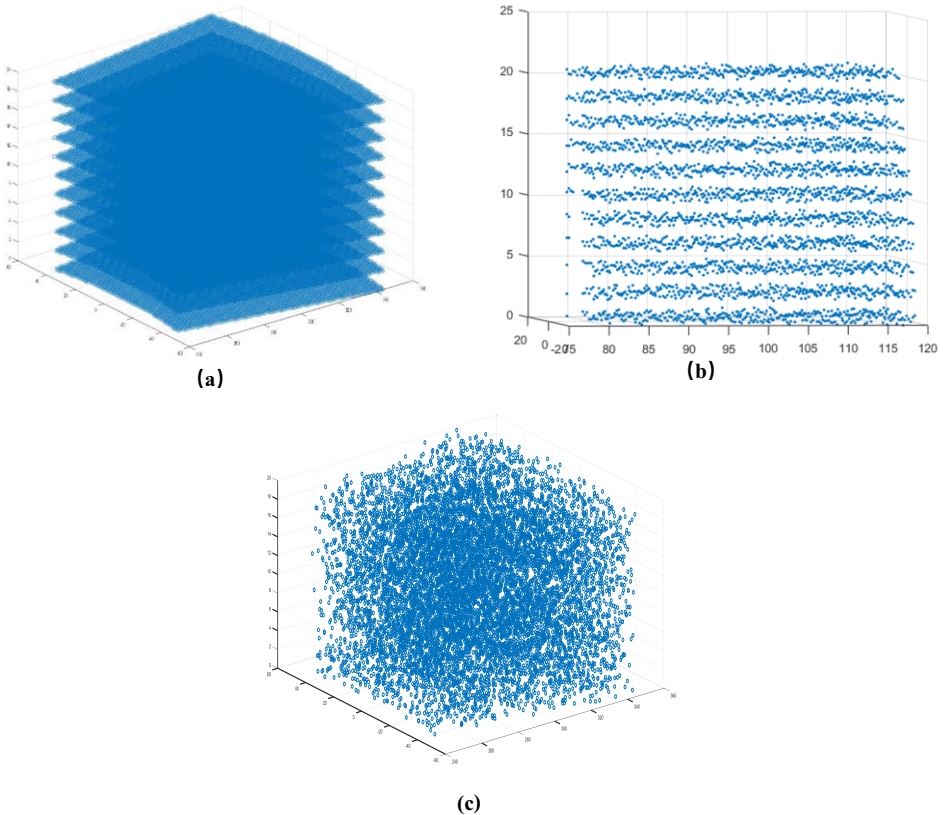
- The first is a layered uniform distribution, and the interval of each reference point is 2m, as shown in Figure.3(a).
- The second type is a layered floating distribution, that is, on the basis of the first type of distribution, a random number is introduced in the position coordinates

of each reference point to make the reference point float to different degrees. A random position float of 0.5m is introduced here, as shown in Figure.3(b).

- The third type is full random distribution. The position distribution of reference points no longer has a clear level, but is randomly distributed in the entire three-dimensional space, and there is no fixed grid spacing of reference points. As shown in Figure.3(c).



**Figure 2.** Three-dimensional scatterer model.



**Figure 3.** (a) Layered uniform distribution. (b) Layered floating distribution. (c) Full random distribution.

2.2. Antenna array

In the two-dimensional positioning, the antenna array adopts a uniform linear array, but in the three-dimensional positioning, an additional elevation angle needs to be introduced to complete the positioning. In this paper, a uniform planar array is introduced to complete the three-dimensional space positioning. The model of the uniform planar array is shown in Figure.4.

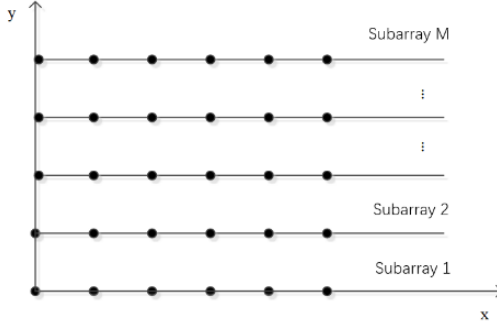


Figure 4. Uniform planar array model.

The XOY plane is an M×N uniform rectangular area array with M antenna elements and N antenna elements on the X axis and Y axis respectively, and the distance between each adjacent antenna element is d. For a uniform planar array, it can simultaneously estimate two-dimensional angle information, namely the azimuth angle and the pitch angle.

Assuming that K signals are incident on the antenna array, regardless of the noise of the system, the signal received by the i-th element is:

$$x_i(t) = \sum_{i=1}^K s_i(t - \tau_{li}) = \sum_{i=1}^K s_i(t) e^{-j\omega_0 \tau_{li}} \tag{1}$$

Write the above formula as a matrix form :

$$\begin{bmatrix} x_1(t) \\ x_2(t) \\ \vdots \\ x_{MN}(t) \end{bmatrix} = \begin{bmatrix} 1 & 1 & \dots & 1 \\ e^{-j\omega_0 \tau_{21}} & e^{-j\omega_0 \tau_{22}} & \dots & e^{-j\omega_0 \tau_{2K}} \\ \vdots & \vdots & \dots & \vdots \\ e^{-j\omega_0 \tau_{MN1}} & e^{-j\omega_0 \tau_{MN2}} & \dots & e^{-j\omega_0 \tau_{MNK}} \end{bmatrix} \begin{bmatrix} s_1(t) \\ s_2(t) \\ \vdots \\ s_K(t) \end{bmatrix} \tag{2}$$

Among them, the delay  $\tau_{li}$  is expressed as:

$$\tau_{li} = \frac{(x_l \cos \theta_l \sin \varphi_l + y_l \sin \theta_l \sin \varphi_l)}{c} \tag{3}$$

The i-th phase shift signal can be expressed as:

$$\phi_{(m,n,i)} = \frac{2\pi}{\lambda} (md \cos \theta_i \sin \varphi_i + nd \sin \theta_i \sin \varphi_i) \tag{4}$$

The response vector can be written as:

$$\mathbf{e}(\theta_i, \varphi_i) = \left[ 1 \quad e^{-j\phi_{(0,1,i)}} \quad \dots \quad e^{-j\phi_{(M-1,N-1,i)}} \right]^T \tag{5}$$

### 2.3. Fingerprint similarity criteria

For the calculation of the distance between fingerprints, due to the needs of the positioning itself and the consideration of the practicality of the algorithm, the overall distance function between the fingerprints should show a monotonous increasing or monotonous decreasing trend. In this section, the Joint Angle Delay Similarity Coefficient (JADSC) is introduced to measure the similarity between fingerprints [6].

For the joint angle delay similarity coefficient at position i and position j, it is defined as:

$$J_{ij} = \max_{n \in (-L+1, L-1)} \left( \frac{1}{N_t^2} [C_i]_t^T [C_j]_{t-n} \right) \tag{6}$$

Notation: Matrix  $C_i$  represents the fingerprint matrix at position I,  $[C_i]_t$  represents the t-th column of the fingerprint matrix, n represents the delay compensation between two fingerprints, and L represents the maximum delay compensation.

In three-dimensional positioning, there may be a value of zero when calculating the similarity of two fingerprints. Here, such a point is called a blind spot. Generally, if the similarity is zero, it can be considered that the similarity between the two fingerprints is very low, and the fingerprint can be discarded during calculation. However, for fingerprints with strong sparsity, some blind spots may be adjacent to the points to be located, which greatly affects the effectiveness of the positioning algorithm.

Considering the expansion of the positioning dimension, in view of the strong sparsity of ADCPM, this article improves JADSC. When calculating the similarity, a very small positive value is introduced into the fingerprint, so as to ensure that the value of JADSC will not be zero. The improved JADSC is as follows:

$$J_{ij} = \max_{n \in (-L+1, L-1)} \left( \frac{1}{N_t^2} [C_i]_t^T [C_j]_{t-n} \right) + \Delta J \tag{7}$$

$\Delta J$  is a minimal positive value, here is  $10^{-10}$ .

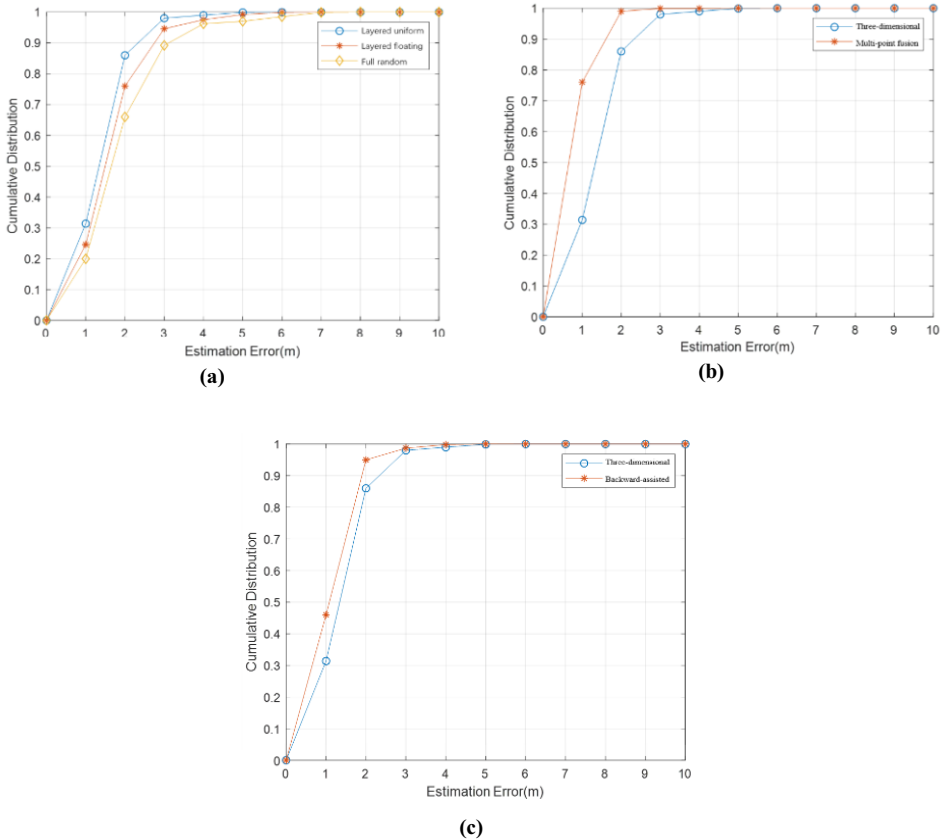
### 2.4. Simulation and analysis

The simulation is based on MATLAB to build a massive MIMO-OFDM single station system. The radius of the area is  $R_{loc}=100m$ , the width is  $W_{loc}=40m$ , the height is  $H_{loc}=20m$ , and the compression ratio  $\rho$  is 1000. The reference point distribution model is the above three distributions. Other relevant parameters are shown in Table 1 [7].

**Table 1.** System Simulation Parameters

<b>OFDM parameters</b>	Transmission bandwidth $B_W$	5-80MHz
	Subcarrier spacing $\Delta f$	15kHz
	Pilot interval $T_g$	4.7 $\mu$ s
	Sampling interval $T_s$	1/(2 · BW)
<b>Antenna parameters</b>	Number of antennas $N_t$	128
	The location of the base station $BS_{pos}$	[0;0]
<b>Other parameters</b>	Scatterer radius $R_{Scat}$	20m
	Scatterer density	0.02/m <sup>2</sup>
	Subpath $N_{Sub}$	40
	Test points N	1000

The three-dimensional space positioning is performed under the three reference point distribution modes, and the number of reference points in the three methods remains the same. The positioning results are shown in Figure.5(a).



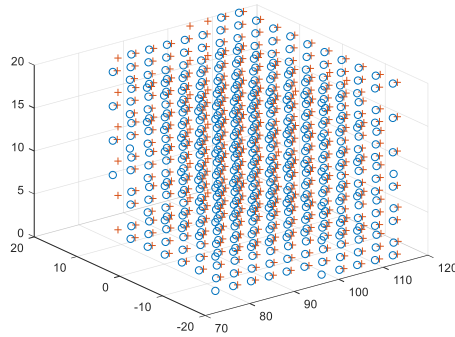
**Figure 5.** (a) Positioning result diagram under three reference point distributions. (b) Multi-point fusion positioning result. (c) Backward-assisted positioning result.

**Simulation analysis:** From the figure, in the three reference point distribution modes, the layered uniform distribution has the highest positioning accuracy, and the fully random distribution has the lowest accuracy. In the fully random distribution, although the characteristics between fingerprints at each reference point will be more obvious, this method will make some information missing, and this imbalance will have a negative impact on the matching algorithm. However, each reference point is uniformly distributed in a layered uniform distribution, and the transition of different fingerprint features is gentle, which is conducive to the matching algorithm.

### 3. Multi-point fusion positioning

#### 3.1. Theoretical basis

In fingerprint positioning, the fingerprint library collects the fingerprint information of the reference points set within the communication range of the base station. Under high base station deployment density, the communication areas of each base station will overlap to different degrees, and the corresponding reference point network may also produce various interlaces. The schematic diagram is shown in Figure.6.



**Figure 6.** Reference point grid.

The reference points between different base stations are staggered, and the points to be located in the staggered area can receive positioning services from two or more base stations. If these base stations all perform separate positioning for the positioning point, the positioning result is consistent with the normal positioning. However, when the reference point networks overlap, these overlapped reference points can be used, and multiple base stations can cooperate with each other to share reference point information, and these interleaved reference points are collectively regarded as another new reference point network. Compared with the reference point network for single-point positioning, the new reference point network has a smaller grid spacing and can provide higher positioning accuracy.

#### 3.2. Simulation and analysis

The simulation parameters under multi-point fusion positioning are consistent with the parameter settings during three-dimensional positioning. In order to simplify the model

and calculations, it is assumed that two base stations have generated the overlap of the reference point network, and the positioning results are shown in Figure.5(b).

**Simulation analysis:** It can be seen from the above figure that multi-point fusion positioning can effectively improve the positioning accuracy, because the overlapped reference point grid is equivalent to reducing the grid spacing after being regarded as a whole. If more base stations coincide with reference points, the positioning accuracy can be further improved. In theory, the reference point network overlap of n base stations can bring up to n times the increase in reference point density. This not only achieve higher positioning accuracy in the matching stage, but also in the acquisition stage can use high grid density based on machine learning algorithms to extract higher-order fingerprint features and improve fingerprint resolution.

### 4. Backward-assisted positioning

#### 4.1. Theoretical basis

As shown in the figure, the actual position of the user is on one side of the line connecting several anchor points. Assuming that the positioning is performed at a fixed time interval  $T_B$ , the positions of the positioning correspond to the five points in the figure. The actual positioning result and the first i points are averaged to obtain the optimized result of the positioning point. For (i+1) points including the actual positioning point of the user, they are distributed symmetrically around the positioning point. Compared with directly positioning the positioning point, the positioning result obtained after taking the average value can be optimized with a probability of  $(1-(1/2)^i)$ .

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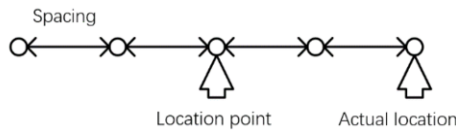


Figure 7. Backward-assisted positioning.

For the distance error between the positioning point and the actual position, a correction value is introduced to correct it. As mentioned above, most users in a short distance are moving in a straight line at a uniform speed, and the speed is  $v_B$ , so the correction value is  $v_B * T_B$ . For example, if the speed of human walking is 1.5m/s, the correction value is 1.5  $T_B$ .



## 4.2. Simulation and analysis

The simulation parameters of the backward-assisted positioning are consistent with the above. Assuming that the user is walking in the positioning scene, the average walking speed is 1.5m/s. The fixed positioning time interval between two points is 0.4s, the number of auxiliary points is 4, and the positioning result is shown in Figure.5(c).

In this simulation test, the average positioning accuracy has increased by 16%. On this basis, the simulation results based on different positioning time intervals and the number of auxiliary positioning points are shown in Table 2.

**Table 2.** Positioning results based on different positioning intervals and auxiliary positioning points.

System positioning time (s)	Number of auxiliary positioning points	Improved average positioning accuracy
0.3	3	6%
0.3	5	16%
0.3	7	15%
0.6	3	13%
0.6	5	16%

**Simulation analysis:** If the time interval is too small or the auxiliary points are too few, the error will be reduced less, but the error caused by the additional correction value will be smaller. As the time interval and the auxiliary points increases, the accuracy of the backward-assisted positioning is gradually improved, but the error caused by the introduced correction value will become larger. And as the time interval further increases, the user's motion trajectory will become unpredictable, and the positions of the auxiliary points may not be symmetrically distributed, thus an additional error will be introduced at this time. Therefore, when performing backward-assisted positioning, it is necessary to find a balance between the above two situations. In addition, this method has strong versatility and can be used in positioning algorithms other than fingerprint positioning.

## 5. Conclusion

This paper studies the fingerprint 3D positioning algorithm, expands the antenna array, provides three reference point distribution models, and improves the fingerprint similarity standard JADSC, which improves the stability of the algorithm. After that, in the scenario of high base station deployment density, using the coincidence of the reference point network, a multi-point fusion positioning technology is proposed to further improve the positioning accuracy of the algorithm. Finally, a backward-assisted positioning method is proposed, which uses the position information of the positioned points to assist the positioning of the current position, and uses statistical laws to improve the positioning accuracy. This method has strong versatility.

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