5G networks three-dimensional indoor positioning based on improved Chan algorithm

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Abstract. In the 3D solution of indoor positioning based on 5G networks, the traditional 3D Chan algorithm cannot solve the problem when all base stations have the same height. Therefore, an improved Chan algorithm is proposed in this paper. Through the improvement of the Chan algorithm operation matrix, the 3D TDOA value and the height value of the barometric height measurement are used to solve the more accurate fixed-point 3D coordinates; And using the benchmark base station sorting selection and the second weighted least squares error absolute value symbol of the Chan algorithm to achieve the effect of reducing the positioning error and expanding the positioning area. According to the actual physical environment and base station distribution, using the improved Chan algorithm, the position coordinates of any point in the three-dimensional space within the coverage of the base station signal can be located. Experiments show that, when all base stations are at the same height, using the solution system proposed in this paper and the improved Chan algorithm, the positioning accuracy is significantly improved compared with the solution result of the traditional two-dimensional Chan algorithm. The positioning result with deviation less than one meter accounted for 84.36%.

Keywords: Indoor Positioning, Chan algorithm, base station at the same height, Solution system

1 Introduction

The arrival of 5G has brought indoor positioning to a new level, such as direct positioning using large-scale Multiple-Input Multiple-Output [1]; Multi-path Angle of Arrival and Time of Arrival indoor 3D positioning based on millimeter wave [2]. The use of 5G related technology for indoor positioning has become the development trend of the future indoor positioning.

In the positioning technology based on 5G signals, the solution methods mainly include TOA and TDOA. The positioning solution method studied in this paper is the TDOA algorithm which can eliminate the time synchronization by using the difference [3].

Among the TDOA solution methods, Chan algorithm is a non-recursive algorithm. Although Chan algorithm can improve the accuracy, it cannot locate the position of the mobile terminal through the base station of the same height. The existing improved

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Chan algorithm methods include residual weighted Chan algorithm improvement [4], Non-Line-Of-Sight (NLOS) condition by adding attenuation factor to smooth [5].

The traditional 3D Chan algorithm requires that the base stations are not all on the same plane. If the height is the same, the calculation matrix in the Chan algorithm will be equal to 0, and the solution cannot be solved. This paper proposes an improved method for the Chan algorithm to locate the point outside the range of the base station， and solve the problem when base station at the same height, and proposes a complete indoor 3D spatial positioning system.

2 System Model

2.1 Lab Environment

This section mainly studies the indoor positioning solution of any point in an underground garage under LOS conditions. In Fig. 1, The five-pointed star is the distribution position of the base station, and each base station is 3 meters high and in the same height plane.

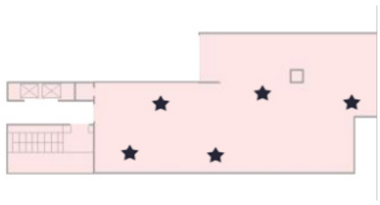

Fig. 1 Experimental physical environment model

2.2 Algorithm Flow

Firstly, the received base station signal is processed, and the reference base station is used to select the reduction error to calculate TDOA value and RSS value. If the to-be-positioned point is located on the vertical line (surface), the improved RSS positioning method is used to estimate the initial point, Finally, combined with the Taylor algorithm, the base station can solve the problem of the position of any mobile terminal in the 3D space in the signal coverage under the same height.

2.3 Base Station Selection

After the second weighted least squares estimation of Chan algorithm, the obtained TDOA measurement error is a square root. For the judgment of positive and negative of this error, the first least squares measurement error discrimination Method is proposed. The specific method will be explained in detail later, and a small amplitude flipping problem caused by the reference base station being too close to the mobile terminal will occur. Therefore, according to the chip value size of the signal sent by each base station, the base station with the second chip value is selected as the reference base station, which is not the closest to the mobile terminal.

2.4 Chan Algorithm Improvement

1)3D TDOA value solving 2D Chan algorithm improvement

When the base stations are of the same height, the height value measured by the air pressure altimetry technique is used as the height of the mobile terminal. In the improvement of the first least squares calculation of the Chan algorithm, the calculation method of the 2D Chan algorithm is used, and one of the arithmetic formulas and the two matrices are improved. The distance calculation formula of the base station and the mobile terminal is improved to Equation 1.

$$r_i = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - H)^2} \quad (1)$$

H is the height of the mobile terminal measured by the air pressure, and (x_i, y_i, z_i) is the coordinate of the ith base station. Since the TDOA is a 3D value, the height difference obtained by the air pressure measurement is added when calculating the distance. The distance from the base station to the mobile terminal of the conventional 2D Chan algorithm in the Ga and h matrices in the first least squares formula of Equation 2 is replaced by the 3D space distance of Equation 1.

$$Z_a = ({G_a}^T \mathrm{Q} G_a)^{-1} {G_a}^T Q^{-1} h \quad (2)$$

Where Q is an identity matrix of n-1 dimensions, n is the number of base stations, n is greater than or equal to 4.

The first least squares of the improved Chan algorithm is solved. However, the error caused by the height difference of the three-dimensional TDOA is not introduced, and the solution result is more accurate. The result obtained is the formula 3.

$$Z_a = (x, y, \mathrm{r})^T \quad (3)$$

In Equation 3, x and y are the obtained x-axis and y-axis coordinates of the mobile terminal, respectively, and r is the distance from the point to be measured to the reference base station.

The above formula is the improvement of the Chan algorithm for solving the 2D coordinates of the 3D TDOA value, and does not introduce the error caused by the height difference. In the second weighted least squares calculation, the original 3D Chan algorithm solving matrix is changed, and the second 3D weighted least squares of the Chan algorithm is improved. The second 3D weighted least squares formula of the improved Chan algorithm uses a 3D least squares formula, as shown in Equation 4:

$$Z_{a1} = ({G_{a1}}^T Q_1 G_{a1})^{-1} {G_{a1}}^T {Q_1}^{-1} h_1 \quad (4)$$

The Ga1 matrix and the Q1 matrix are shown in Equation 5 and Equation 6: matrix and the Q1 matrix are shown in Equation 5 and Equation 6:

$$Q_1 = 4\mathrm{B}\,\mathrm{cov}(Z_a)\mathrm{B} \quad (5)$$

$$\mathrm{cov}(Z_a) = ({G_a}' Q^{-1} {G_a}')^{-1} \quad (6)$$

The third column of the B matrix in Equation 5 are improved, and the height value obtained by the barometric height measurement is introduced, and the matrix inversion is prevented. The singular value cannot be solved. The specific improved formula is shown in Equation 7, Equation 8 and Equation 9.

$$h_1 = \begin{pmatrix} (x - x_1)^2 \\ (y - y_1)^2 \\ H^2 \\ r^2 \end{pmatrix} \quad (7)$$

$$B = \begin{pmatrix} (x-x_1)^2 & 0 & 0 & 0 \\ 0 & (y-y_1)^2 & 0 & 0 \\ 0 & 0 & (H-z_1)^2 & 0 \\ 0 & 0 & 0 & r^2 \end{pmatrix} \tag{8}$$

$$G_a{}' = \begin{pmatrix} x_{2,1} & y_{2,1} & 0 & r_{2,1} \\ \vdots & \vdots & \vdots & \vdots \\ x_{n,1} & y_{n,1} & n-2 & r_{n,1} \end{pmatrix} \tag{9}$$

The second weighted least squares calculation of the improved Chan algorithm is to use the first modified Chan algorithm to calculate the x, y coordinates and r to perform the 3D least squares weighting calculation, and introduce the height H obtained by the barometric height measurement into the calculation matrix. At the same time, the height value of the $G_a{}'$matrix is improved, so that all the base stations can perform the modified Chan algorithm solution when they are on the same height plane, and the 3D TDOA error caused by the height difference is not introduced. The final solution yields the formula as shown in Equation 10:

$$Z_{a1} = \begin{pmatrix} (x-x_1)^2 \\ (y-y_1)^2 \\ H_1 \end{pmatrix} \tag{10}$$

Finding H_1 has no practical significance, and the obtained $(x-x_1)^2$ and $(y-y_1)^2$are the squares of the TDOA measurement error in the x and y directions.

2）Improved Chan algorithm to expand the locator range

In the original Chan algorithm, only the point coordinates in the area enclosed by each base station can be located, so the utility is not high. In response to this problem, this paper proposes the first least squares measurement error discriminant method. After the first weighted least squares solution of the Chan algorithm, Δx, Δy, and Δz with positive and negative values are obtained, and the positive and negative values of Δx, Δy, and Δz are obtained according to the first time, respectively, and the corresponding correspondence is obtained for the second time. By this method, it is possible to locate any mobile terminal location within the coverage of the base station signal.

2.5 RSS Initial Mobile Terminal Location Solution

When the location of the mobile terminal is on the vertical line (surface) in the base station, the position of the point cannot be located. The RSS algorithm uses the attenuation characteristics of the signal strength in a uniform medium to roughly estimate the position of the mobile terminal.

$$d = 10^{\left(\frac{|rssi|-A}{10n}\right)} \tag{13}$$

In Equation 13, d is the distance from the base station to the mobile terminal, rssi is the received signal strength, A is the signal strength when the transmitting end is different from the receiving end by 1 meter, and n is the environmental attenuation factor.

The purpose of the solution here is to give the estimated initial positioning point in the correct region to perform the iterative optimization solution of the Taylor algorithm. First, the strength of each base station positioning signal is sorted, and the weighted foot of the two base stations is selected according to the field strength, and the vertical plane is made.

$$\frac{d_2}{d_1} = 10^{\left(\frac{rssi_1 - rssi_2}{10}\right)} \tag{14}$$

Then, the geometric center of gravity is calculated according to the space enclosed by the weighted vertical plane of each of the three base stations, and the initial positioning point estimated by the RSSI positioning of the three base stations is calculated.

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \sum_{i=1}^{N} \mu_i \begin{pmatrix} x_i \\ y_i \\ z_i \end{pmatrix} \tag{15}$$

In Equation 15, N is the number of RSSI positioning results, and μ is a weighting factor positively correlated with the signal strength of the base station group, and x, y, and z are 3D of each group of positioning estimation results. Finally, the positioning result of each group of base stations is weighted according to the signal strength of the base station in the group to obtain an optimal initial positioning point.

3 Simulation And Experiment

3.1 Simulation Comparison

1)Benchmark selection comparison

In order to prevent other Chan algorithm improvements from affecting the comparison results, this paper simulates the base stations with different heights. Fig. 2 is a simulation result of the mobile terminal near the base station, and the triangle represents the location of the base station. A total of five base stations are set, the circle is the actual position of the mobile terminal, x is the position of the improved positioning point. The lower graph in Fig. 2 is an enlarged view of the above graph in the vicinity of the mobile terminal. The absolute values of the x and z coordinate differences of the two positioning results are less than 0.01 m, which can be ignored, and the y-coordinate values differ greatly. When the base station and the mobile terminal is very close, the decision method that is not sorted by the base station may cause the final result deviation to be excessive, and the improved decision can avoid this problem and improve the positioning accuracy.

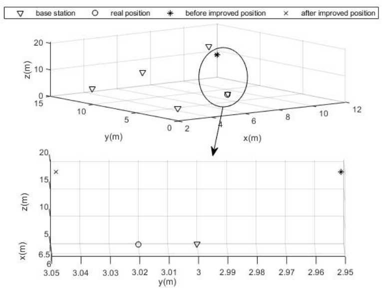

Fig. 2 Comparison of different selected base stations

2)Improved comparison of Chan algorithm for the same height base station

When all base stations are of the same height, the improved Chan algorithm uses the standard TDOA value and the test point height value to solve.

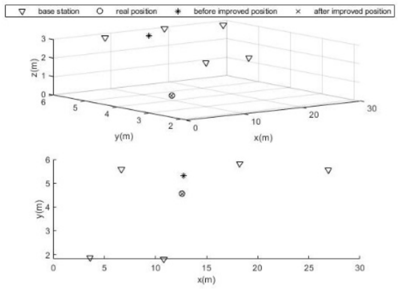

Fig. 3 Comparison of the improved algorithm of the same base station Chan algorithm

The triangle represents the location of the base station. All base stations are 3 meters high. The circle represents the real position of the point to be located. x is the improved Chan algorithm positioning result in this paper. The upper picture is a three-dimensional space picture, and the lower picture is a top view of the above three-dimensional space picture. Since the traditional Chan algorithm cannot solve the TDOA error caused by the height difference, the positioning result will generate a large offset, However, the improved Chan algorithm in this paper will also bring the height into the calculation, which solves the problem that the singular value of the Chan algorithm matrix cannot be calculated when all the base stations are the same, and the settlement result is basically the same as the real position of the to-be-positioned point when using the standard TDOA solution.

3)Expanding the positioning range

In order to prevent other Chan algorithm improvements from affecting the comparison results, this paper simulates base stations with different heights. The only difference is the second weighting of the 3D Chan algorithm. The absolute value of each coordinate axis error obtained by least squares is handled differently.

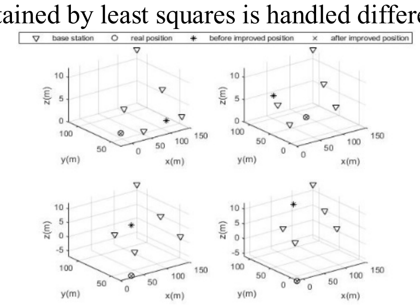

Fig. 4 Improved comparison of mobile terminals outside the location of the Chan algorithm

When the discriminant condition is not improved, the Chan algorithm locates a point outside the area enclosed by the base station, and there is a phenomenon that the error is positive or negative, which leads to double error and cannot accurately locate the outer point of the area. However, the improved Chan algorithm has no such defect.

3.2 Experimental Test Comparison

This section collected 50 fixed-point TDOA data randomly and collected 200,000 data for each fixed point to solve, where the environment is basically unchanged and the device is stationary. Due to space limitations, this paper randomly selects a set of 50 fixed points in the field to carry out the traditional 2D Chan algorithm solution and the improved Chan algorithm solution for comparative analysis.

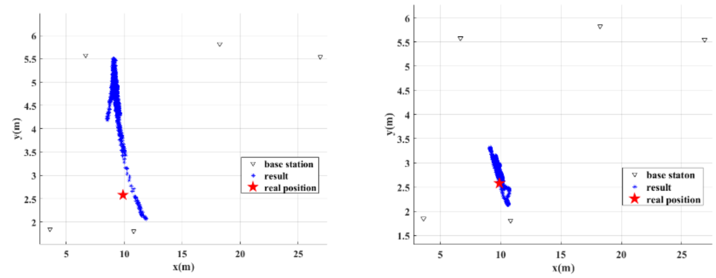

Fig. 5-6 Traditional 2D Chan algorithm solution result vs Improved Chan algorithm solution result

Fig. 5 and Fig. 6 show the results of the traditional 2D Chan algorithm solution and the improved Chan algorithm solution. Multipath interference processing is performed for the physical environment, and only the LOS signal is taken to reduce the influence of multipath interference. The triangle in the figure is the location of the base station, the blue asterisk is the positioning solution result, and the red five-pointed star is the real position of the test point. Compared with the results of the traditional 2D Chan algorithm in Fig. 5, the results of the modified Chan algorithm in Fig. 6 are significantly improved. Moreover, when the solution result exceeds the range enclosed by the base station, a phenomenon of inversion with respect to the connection boundary of the base station occurs. As shown in Fig. 5, the positioning result dot is flipped at y = 5.58m. Through the improvement of the calculation matrix, the same height base station can also correctly locate the point coordinates of the 3D space.

Fig. 7 is a CDF diagram of the error distances of the two algorithms. The blue line is the improved Chan algorithm and the red line is the traditional 2D Chan algorithm. According to the test results, more than 84.63% of the test results reached the m-level positioning, which is a qualitative leap compared with the results of the traditional 2D Chan algorithm.

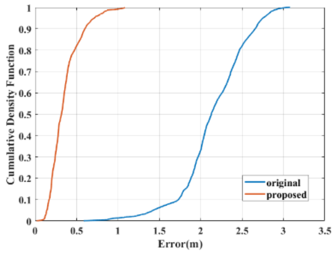

Fig. 7 Two Chan algorithm solution error distance CDF diagram

4 Conclusion

The improved Chan algorithm solves the problem that the same height base station cannot use the Chan algorithm to accurately locate the mobile terminal position. In the second weighted least squares of the Chan algorithm, the discriminant of the absolute value of the error is added, and the positioning range is raised from the point coordinates in the range enclosed by the base stations to all points in the coverage of the base station signal. Through the improvement of the above Chan algorithm, the problem that the same height base station is effectively solved, the positioning range is expanded, the positioning error is reduced, and the Chan algorithm is more suitable for engineering applications. The innovative RSS algorithm is used to compensate for the defect that the Chan algorithm cannot locate the mobile terminal position on the vertical line, which makes this set of TDOA solution system more widely applicable and can be applied to various experimental physics.

References

1. N. Garcia, H. Wymeersch, E. G. Larsson, A. M. Haimovich and M. Coulon, "Direct Localization for Massive MIMO," in IEEE Transactions on Signal Processing, vol. 65, no. 10, pp. 2475-2487, 15 May15, 2017.
2. Y. Jia, H. Tian, S. Fan and B. Liu, "Motion Feature and Millimeter Wave Multi-path AoA-ToA Based 3D Indoor Positioning," 2018 IEEE 29th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), Bologna, 2018, pp. 1-7.
3. Baoping Q, Gang S, Zhanrong J. An improved TDOA location algorithm in LOS environment[C]. Intelligent Human-Machine Systems and Cybernetics (IHMSC), 2012 4th International Conference on. IEEE, 2012, P70-73
4. Y. Zhong, T. Wang, Y. Liu and X. Luo, "Indoor UWB Location Based on Residual Weighted Chan Algorithm," 2018 7th International Conference on Digital Home (ICDH), Guilin, China, 2018, pp. 274-279.
5. S. Bao, L. Yan and Y. Bao, "Three-dimensional indoor positioning based on wireless mobile communication network," 2017 First International Conference on Electronics Instrumentation & Information Systems (EIIS), Harbin, 2017, pp. 1-4.