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AN INDOOR LOCATION TRACKING OPTIMIZATION ALGORITHM BASED ON NLOS MODEL

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Abstract. *In the NLOS environment, the signal intensity will become weaker in the transmission process because of the loss of occlusion, reflection and absorption. In order to minimize the position estimation error, this paper presents an indoor location tracking optimization algorithm based on NLOS (Non-Line-of-Sight) model. Firstly, the measured data is linearly fitted to obtain their quantitative relation. Then, an optimal problem about indoor location is given after a proper deformation. The position coordinate of the hand-held mobile terminal is established by the least squares method combined with the constraint of the over-determined equation. Combined with the localization algorithm, the target tracking trajectory of the terminal is finally obtained. The algorithm increases the positioning accuracy of the hand-held mobile terminal equipment by 98% and the positioning error is reduced to less than 0.2 m. In addition, the resulting trajectory error approaches zero without manual fitting. The method has the advantages of small computation complexity and simple structure, which can satisfy the requirements of indoor application in the real-life application.*
Keywords: NLOS, Indoor location, Least squares method, Optimal fitting model

1. **Introduction.** The existing GPS positioning technology has been widely used with the development of smart phones [1,2]. However, in many areas, such as indoor, underground, high-rise buildings and other urban areas, the performance of GPS positioning is still poor. The positioning system based on wireless network has advantages over GPS in terms of breadth and depth of coverage [3]. The demand of modern commercial communication network of indoor positioning is to use the base station as little as possible to complete the positioning of the terminal equipment [4]. An indoor positioning algorithm with the advantages of fast convergence speed, robustness to interference and noise is also desirable.

Non-Line-of-Sight (NLOS) will affect the accuracy of signal measurement. To solve this problem, the LLOP (Linear Line of Position) [5-7] method is a classic TOA (Time of Arrival) positioning method. In this method, three intersecting circles are translated into two intersecting lines. A number of measuring points can be obtained through multiple measurements and calculations and the centroid is calculated to determine the location of the mobile station. Besides, the RSA (Range Scaling Algorithm) method is also proposed. It uses the scale factor to represent the extent between the calculated and the real distance. It still cannot meet the requirements, although the positioning accuracy has been improved greatly. The initial value of LLOP is also used to select at least two effective base stations, and then the TOA value of the base station is selected as circular intersection for the second positioning under the optimization rules [8], which finally determines the coordinates of the mobile station.

In this paper, an indoor location tracking optimization algorithm based on NLOS model has been proposed. TOA based mobile localization and its performance under NLOS conditions have been extensively studied in [9-11]. Firstly, the algorithm obtains the optimal accuracy in the presence of errors, as the data are analyzed and processed on the basis of the traditional TOA algorithm [12-14], and the error is integrated under the premise of acknowledging the error existence. Then the optimization algorithm of the mobile terminal is received by using the overdetermined equation as the constraint condition [15]. The paper is mainly aimed at the existence of errors in the actual environment, which also ensures simple structure, fast calculation speed and to be improved positioning accuracy [16-18].

2. **Indoor Positioning and Tracking Optimization Algorithm.** Chan algorithm is a kind of TDOA technology, with the analytic solutions based on location algorithm. In many TDOA based localization algorithms [1,9,12], Chan algorithm has been widely used. This is mainly because the algorithm has three major advantages: the algorithm does not require the initial value; only two iterations to obtain the final result; the positioning accuracy of the algorithm can reach the Cramer Rao lower bound in the line of sight environment. Therefore, Chan's positioning algorithm is a very useful way, suitable for practical engineering. It can be seen that most of the existing indoor positioning algorithms are based on Chan [16-18] algorithm through a large number of literature data. Chan algorithm is a solution of the non recursive hyperbolic equations with analytic expression, which is one of the classical algorithms based on TDOA parameter estimation. However, the algorithm has a large error for the practical problems of this paper, which is not suitable to solve the existing problems.

2.1. **Test data analysis.** It is assumed that there are M base stations distributed randomly in three-dimensional space. The coordinates of the measured points are (x, y); the base station coordinates are (x_i, y_i); the measured distance to the point to be measured is s_i, and the actual distance is s_{ir}.

Through observation and analysis on the test data obtained, one reason is that the value of Z ranges from $(1, 2)$, which can be ignored relative to the value of (X, Y); the other reason is that there is no obvious difference between the spheres in the three-dimensional space, so the distance between the hand-held terminal and the base station is taken as the radius of the circle in the analysis of MATLAB data, which projects into the plane of XOY. The obtained results are shown in Figure 1.

In Figure 1, the center of the intersection is the projection of the XOY plane of the real terminal. The conclusion can be obtained from the figure.

1) With the increase of the distance between the mobile terminal and the base station (i.e., the circle radius in the image), the larger the circle radius, the larger the distance between the circle and the coordinates. Finally, the distance error will increase.

2) It can be intuitively seen that all circles contain the center of the intersection. The smaller the radius, the closer the circle is to the center of the intersection. It is found that there is a good linear relationship between the measured data and the actual distance. The map is shown in Figure 2:

$$s_i - s_{ir} = s_i * a + b_i. \tag{1}$$

From Formula (1) we can get the following proportional relationship:

$$s_i = \frac{s_{ir}}{b - a} + \frac{b_i}{1 - a} \tag{2}$$

where $k = \frac{1}{1-a}$, $s_i = c * t_i$ indicates the measured distance, a is a constant, b_i is the offset, (The c is said the radio signal propagation velocity $3 * 10^8$m/s) and s_{ir} represents the actual distance from the i-th base station to the hand-held terminal. t_i represents the

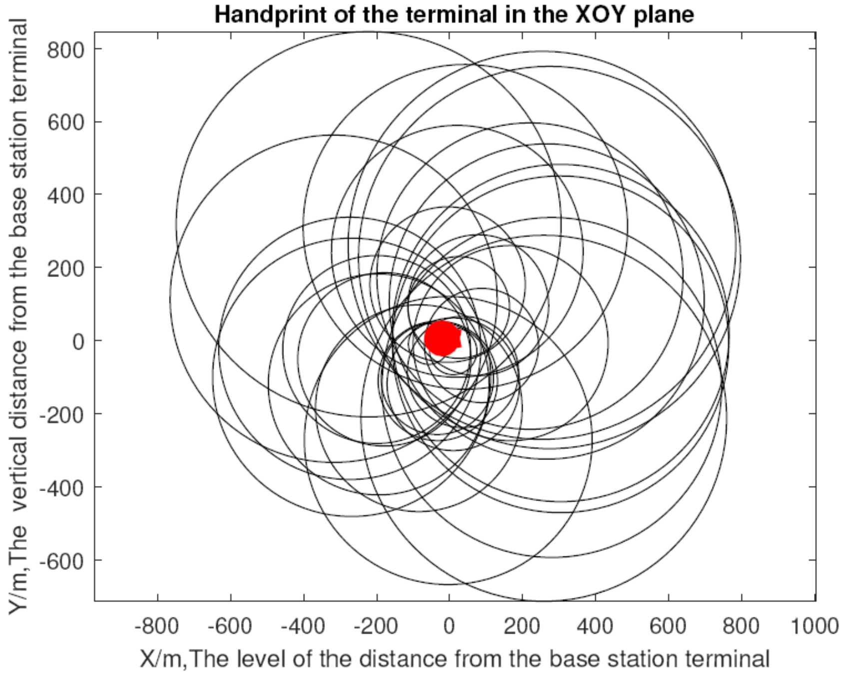

Figure 1. Handprint of the terminal in the XOY plane

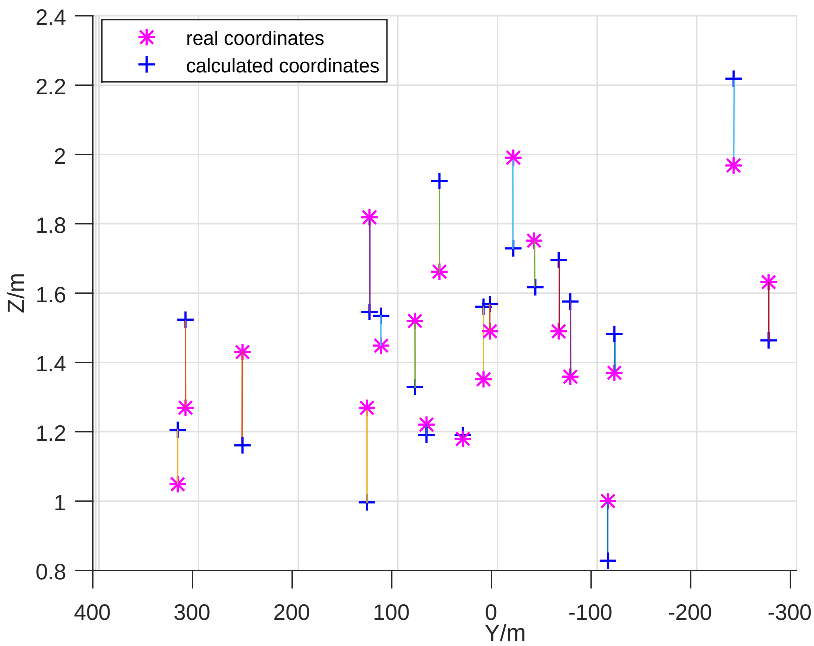

Figure 2. Measure the coordinates and calculate the relationship between the coordinates.

measurement data of the hand-held terminal to the i-th base station TOA. In order to simplify the model, Formula (1) can be deformed:

$$s_i - s_{ir} \approx s_i * a, \quad i = 1, 2, 3, \ldots, M. \tag{3}$$

2.2. **Indoor positioning and tracking algorithm.** It is necessary to study the existing tracking algorithm for the situation of dynamic targets. Multipath and Non-Line-of-Sight (NLOS) propagation are two important factors that affect the tracking accuracy. According to the fact that the indoor target may be moved, it is very necessary to do research on the existing tracking algorithm. At present, the mature algorithm is Kalman filter (Kalman Filter, KF) and its extended filtering algorithm. At the same time, the particle filtering also gradually shows its advantages in target tracking. However, these algorithms cannot adapt to the trajectory tracking in complex environments. Based on the test data provided by HUAWEI and the indoor location algorithm, a robust tracking algorithm is presented. The following describes its derivation process.

The distance between the terminal and the base station can be calculated from the given data. Additionally, the true coordinates of all the base stations are known. From the data given to the coordinates of the two points, which can be obtained by the theorem of the following formula:

$$s_{ir} = \sqrt{(x_i - x)^2 + (y_i - y)^2} \tag{4}$$

where (x_i, y_i, z_i) indicates the actual distance to the hand-held terminal base stations and (x, y, z) the actual coordinates of hand-held terminal. From Formula (3) it can be deduced:

$$s_i = \frac{s_{ir}}{1-a} = k * s_{ir}. \tag{5}$$

Formula (5) into Formula (4), finishing the following formula it can be obtained:

$$\frac{(s_i)^2}{k^2} = (x_i - x)^2 + (y_i - y)^2. \tag{6}$$

Formula (6) can be summarized as follows to simplify the relationship:

$$\frac{(s_i)^2}{k^2} = (R_i)^2 + R^2 - 2x_i x - 2y_i y$$

where $R_i^2 = (x_i)^2 + (y_i)^2$ indicates the distance from the origin to the hand-held terminal, $R^2 = x^2 + y^2$ indicates the base station to the distance from the origin.

Further finishing available:

$$R_i^2 = 2(x_i)x + 2(y_i)y - R^2 + \frac{(s_i)^2}{k^2}. \tag{7}$$

According to Formula (7), the following matrix relations can be listed:

$$D = A * Z \tag{8}$$

where: $A = \begin{bmatrix} 2x_1 & 2y_1 & 1 & (s_1)^2 \\ 2x_2 & 2y_2 & 1 & (s_2)^2 \\ 2x_3 & 2y_3 & 1 & (s_3)^2 \\ \vdots & \vdots & \vdots & \vdots \\ 2x_M & 2y_M & 1 & (s_M)^2 \end{bmatrix}$, $Z = \begin{bmatrix} x & y & R^2 & \frac{1}{k^2} \end{bmatrix}^{\mathrm{T}}$, $D = \begin{bmatrix} R_1^2 & R_2^2 & R_3^2 & \cdots & R_M^2 \end{bmatrix}^{\mathrm{T}}$.

The addition of constraints to the least squares method is intended to prevent the occurrence of over-fitting. In order to further optimize the algorithm, the formula adds a regular term to prevent singularity. Through the effective solution of the model get the hand-held terminal coordinates.

$$\arg\min_z \left(\frac{1}{2}(||D - A * z||)^2 + \frac{\lambda}{2}(||z||)^2 \right). \tag{9}$$

The above problem is convex optimization problem. The point where the gradient of $f(z)$ is zero is the optimal solution.

$$f'(z) = A^{\mathrm{T}}(D - Az) + \lambda z = 0.$$

$(A^{\mathrm{T}}A + \lambda I)z = A^{\mathrm{T}}D$, where $(A^{\mathrm{T}}A + \lambda I)$ is definite.

Then:

$$Z = (A^{\mathrm{T}}A + \lambda I)^{-1}A^{\mathrm{T}}D.$$

3. Calculation Results and Analysis.

3.1. Indoor positioning results. The terminal coordinate model is established through the above process, as shown in Formula (9). The simulation is conducted in the following in accordance with test data in actual scene of HUAWEI. The specific flow chart shown in Figure 3 is compared with the algorithm in the literature.

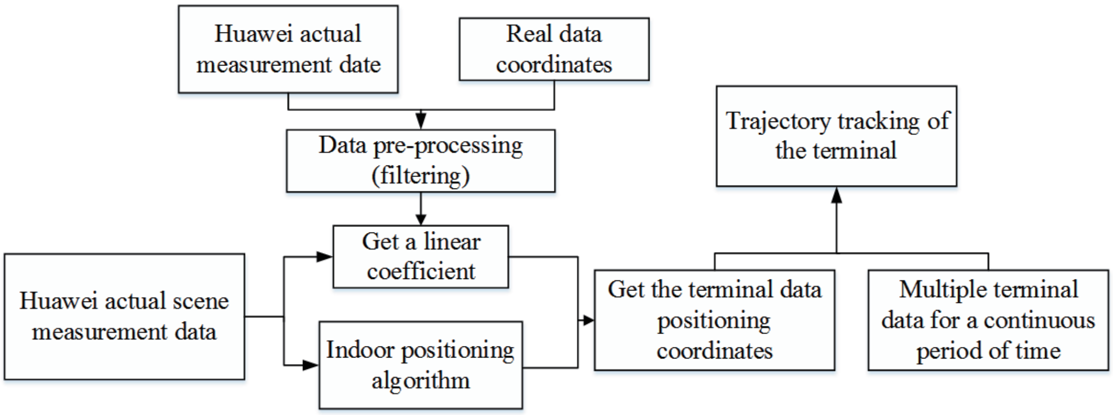

FIGURE 3. Flow chart of indoor localization and tracking algorithm

Through the preliminary data processing, the absolute value of the calculated coordinates and the actual coordinates as well as the coordinate difference are obtained (as shown in Table 1).

TABLE 1. Calculate the absolute value of the coordinate and the actual coordinate and the coordinate difference.

real data		**calculate data**		***x*, *y* coordinate error absolute value**		**terminal mean square error/dB**
x	y	x	y	δx	δy	$\sqrt{(\delta x)^2+(\delta y)^2}$
−21.19	4.48	−21.269	4.5721	0.079	0.0921	**0.12**
−81.14	58.24	−81.129	58.351	0.011	0.111	**0.11**
−296.06	−20.15	−296.14	−20.085	0.08	0.065	**0.10**
86.29	−111.06	86.281	−111.12	0.009	0.06	**0.06**
−31.26	244.68	−31.258	244.63	0.002	0.05	**0.05**
255.34	66.63	255.34	66.667	0	0.037	**0.04**
52.84	−113.40	52.82	−113.38	0.022	0.025	**0.03**
48.78	4.96	48.72	4.91	0.061	0.052	**0.08**
279.77	12.63	279.86	12.72	0.090	0.086	**0.12**
−163.41	30.95	−163.33	31.07	0.081	0.119	**0.14**

The error absolute value of coordinate can be seen directly from the data in the table, which is chose to 0 by calculation. The various algorithms introduced in [1] deduct the terminal position with the geometric definition based on the coordinates of the 3 base stations, and make multiple measurement for the average in eliminating errors as much as possible to improve positioning accuracy. In this paper, we use the above data processing to find the relationship between the error and the actual positioning coordinates, so that the positioning accuracy of the maximum error attains below 0.5 m.

3.2. **Error analysis.** The TOA method can better reduce the influence of the NLOS error in dealing with the accuracy of NLOS, and get more accurate data. Table 2 is the comparison of the algorithms (N represents the maximum NLOS error propagation). LLOP: (Linear Line of Position).

Table 2. Measurement of mean square error comparison

N	Chan algorithm of TDOA error value/dB	LLOP algorithm TOA mean square error value/dB	The mean square error of the optimization algorithm/dB	The mean square error of this algorithm /dB (regardless of N)
1	15.3467	1.1141	0.5506	< 0.50
5	80.9581	3.9328	2.1272	< 0.50
10	155.3146	16.3625	6.8164	< 0.50
20	107.9194	24.9758	10.0488	< 0.50
30	75.5081	69.3596	20.9839	< 0.50

As can be seen from the table, even in the case of small NLOS (N = 1), the impact of bad base station on TDOA algorithm is great. The mean square error of the algorithm is improved obviously after optimization. With the increase of NLOS error, the measured value of TOA is obviously better than that of LLOP algorithm and the optimized TOA algorithm. In the case that NLOS disturbs and the base station cannot achieve better, in the TOA based localization algorithm of this paper, it does not consider the value of N, does not need to generate random numbers to fit the error caused by repeated measurements. Instead, we use the error to eliminate the error directly, and eliminate the interference of the number of base stations and the sight distance and non line of sight. The algorithm has robustness to the error and high accuracy through the pretreatment of the data.

3.3. **Indoor tracking results and error analysis.** The trajectory model of the terminal coordinates is established by the above detailed algorithmic process, as shown in Formula (9). The following will be through the use of test data in MATLAB processing and model simulation. The tracking algorithm in [4] is a target tracking algorithm based on TOA.

It can be seen that the trajectory data of the mobile terminal stimulated in the model built of this paper, have basically no interference points. All the data are fitted to the true distance. Then it can be inferred that, the model has good robustness in the trajectory localization of the terminal indoor coordinates, which is able to overcome some of the non-human interference information. After the local amplification of the graph, the curve is observed to be composed of more than 1 thousand scattered points, which is not human fitting. The trajectory fitting has high extent and no need to repair. Therefore, the positioning accuracy meets the actual demand and has good robustness.

4. **Conclusion.** In this paper, the 5 sets of data (the 5500 terminals) in the test sample are investigated firstly; the relationship between the TOA (Time of Arrival) transformation distance and the true one calculated by the coordinates is studied; then, the data are pre-denoised, and the best fitting model between the measured data and the real data is established; the least squares model based on the over-determined equation is obtained combined with super qualitative of the real model, which gets hand-held terminal coordinates. After a simple treatment the true value of the TOA can be obtained. Under this algorithm, the positioning accuracy of 98% terminal devices rises to below 0.2 m, and the maximum error is not more than 0.5 m, which improves the indoor positioning accuracy greatly. Moreover, the error of the obtained trajectory is close to 0 without manual

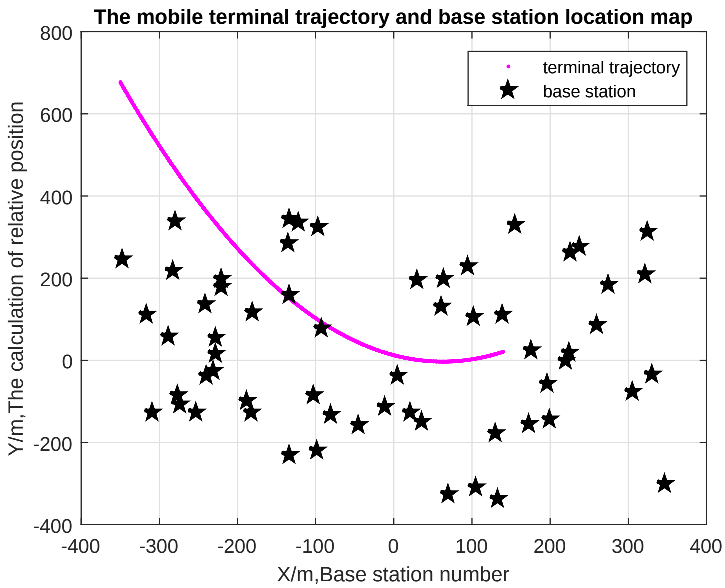

FIGURE 4. Indoor terminal tracking results. It can be seen that the moving track of the mobile terminal has no interference at the simulation data under the model established in this paper. All the data are basically equal to the real distance after fitting. Moreover, the curve fitted is smooth without burr. After the local amplification, the basic is one of the scattered points, it is shown that the graph is composed of more than 1000 scattered points, and is not artificial fitting.

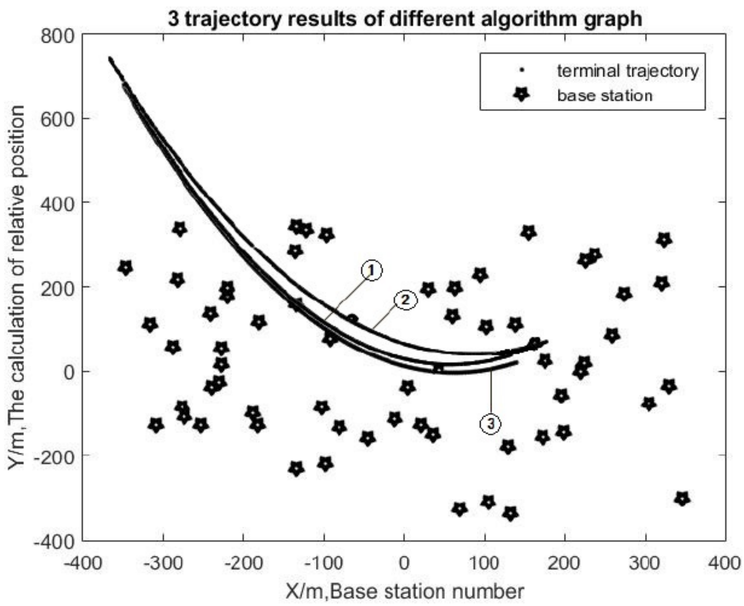

FIGURE 5. Comparison of trajectory fitting of mobile terminal. ③ represents the original trajectory, ① represents the trajectory of the algorithm calculation, and ② represents the graph obtained in the algorithm [4]. Here you can see the visual mobile terminal which is obtained by this algorithm tends to be consistent in the indoor trajectory and the actual data fitting of the trajectory.

fitting. Then, the optimal fitting model is established by using the indoor positioning algorithm, and a series of terminal position coordinates is obtained. It can be seen that the trajectory is smooth and has no deviation from the terminal trajectory drawn.

Here are some research topics that will be studied in the future.

1) It can be extended to the appropriate test environment, the test environment is not limited to the interior.

2) It can be calculated by the real distance and TOA distance error cannot satisfy the linear relationship, as long as there is a clear nonlinear or linear relationship, we can solve the three-dimensional space positioning through the modeling process of similar problems.

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