Wireless Communication Base Station-Based Indoor 3D Target Positioning Research

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Abstract

In this paper, the improved Chan algorithm based on signal TOA data (the improvement using the weighted minimum mean square error method) is used to calculate the terminal position coordinates, and then the partial least squares regression analysis is used to perform regression analysis and error modeling on the position coordinate results. Finally, an accurate estimation of the three-dimensional position coordinates of the terminal is obtained. According to the model solution, the algorithm designed in this paper can effectively eliminate the non-line-of-sight propagation environment (NLOS) error and obtain an accurate estimation of the terminal position.

Keywords

Improved Chan Algorithm, Partial Least-square Method, 3D Target Positioning.

1. Introduction

With the rapid development of wireless communication networks and mobile Internet, providing location based service (Location Based Service, LBS) has become one of the most important research hotspots. From traditional GPS navigation to other LBSs and social software such as Facebook, the basis for realizing its function is to receive and send signals from mobile terminal devices to obtain measurement information of distance and angle and so on, and to use positioning algorithm transforms the measurement information into coordinate information [1].

Although commercial GPS has been widely used with the development of smart phones, GPS positioning performance is poor in many scenes such as indoor, underground, urban areas with many high buildings. It has been paid more and more attention by operators and researchers due to the advantages of wireless communication base station(WCBS) based positioning system than GPS in terms of coverage and depth. CHAN algorithm is a classic error correction algorithm based on the time difference of signal arrival. It does not require recursion to give the closed solution of the hyperbola equation, which has the advantages of high precision in the ideal Gaussian noise environment and is very suitable for practical engineering application [2]. However, the performance of CHAN algorithm has a significant decrease in non-line-of-sight environment [3].The modern commercial communication network has the following three requirements for 3D positioning algorithm: 1) complete the positioning of the terminal equipment using the minimum number of base stations; 2) localization algorithm converges fast; 3) The algorithm is robust to interference and noise.

Compared to GPS and other commercial satellite positioning system, WCBS-based indoor 3D target positioning system has the following characteristics: 1) The target area of communication base station is the scene that GPS and other satellite positioning system cannot be positioned. GPS systems cannot meet the positioning needs in the high-rise of city, the building interior, the underground car park and so on. However, the base stations and terminals of these application scenarios are dense.2) The radio signal are transmitted through the wall multiple reflections, indoor refraction and absorption of objects in the indoor environment. These physical factors can cause severe noise such as distance, angle information measured by the WCBS.

The contribution and innovation of this paper are as follows:

1)Firstly, the improved Chan algorithm is used to quickly identify the scene and realize the fast positioning, then adopt the iterative method based on the NLOS environment error estimation model to establish a precise model which reduces the positioning error to 0.1 meters below of XY plane and 2 meters below of Z-vertical height. The improved Chan algorithm can adapt the dynamic change of indoor scene, and we find that the error of locating coordinates in NLOS environment is Rayleigh distribution.

2) Under the given target location scenario, we get the minimum number of base station that can be accurately positioned.

The rest of this article is organized as follows. Section II gives a detailed problem formulation and algorithm details. Simulation evaluation results are given in Section III.The conclusions and future work are presented IV.

2. Robust localization in indoor 3D environment

The frequently used notations in this paper are summarized in Table 1.

Table 1 Frequently Used Mathematical Notations

Notation	Definition
M	The number of WCBS
(x_i, y_i, z_i)	The Position coordinate of the i-th handheld terminal(unknown)
(X_j, Y_j, Z_j)	The Position coordinate of the j-th base station(known)
τ_{ij}	TOA data measured by WCBS
τ	The asynchronous error of the clock that takes the random number between -200ns to 200ns.
R_{ij}	Real distance between base station and terminal
$\hat{R}_{ij}$	Measurement distance between base station and terminal
e_{ij}	NLOS propagation environmental error
n_{ij}	Gaussian white noise with mean 0 and variance σ_j^2
c	The propagation speed of the radio signal, the value is 3×10^8 m/s

From Table 1 to establish the equation below:

$$\begin{aligned}
\hat{R}_{ij} &= c\tau_{ij} = R_{ij} + n_{ij} + e_{ij} + \tau \\
R_{ij}^2 &= \left(X_j - x_i\right)^2 + \left(Y_j - y_i\right)^2 + \left(Z_j - z_i\right)^2 \\
&= K_j - 2X_j x_i - 2Y_j y_i - 2Z_j z_i + R,\ j = 1,2,\dots,M
\end{aligned} \tag{1}$$

where: $K_j = X_j^2 + Y_j^2 + Z_j^2,\ j = 1,2,3,\dots, R = x_i^2 + y_i^2 + z_i^2$

Let $z_\alpha = [z_P^T, R]^T$ be an unknown vector, where $z_p = [x_i, y_i, z_i]^T$ .A linear equation Group with z_α as variable can be established by Eq.(1):

$$h = G_\alpha z_\alpha \tag{2}$$

The error vector corresponding to the terminal estimation position is as follows:

$$\psi = h - G_\alpha z_\alpha^0 \tag{3}$$

where: z_α^0- z_α value corresponding to the actual position of the terminal.

$$h=\begin{bmatrix} R_1^2-K_1 \\ R_2^2-K_2 \\ \vdots \\ R_M^2-K_M \end{bmatrix}, G_\alpha=\begin{bmatrix} -2X_1 & -2Y_1 & -2Z_1 & 1 \\ -2X_2 & -2Y_2 & -2Z_2 & 1 \\ \vdots & \vdots & \vdots & \vdots \\ -2X_M & -2Y_M & -2Z_M & 1 \end{bmatrix}$$

The covariance matrix Q of TOA data is used to approximate the covariance matrix of the error ψ by using the weighted least square method [4],then z_α can be given as follows:

$$z_\alpha=\arg\min\left\{\left(h-G_\alpha z_\alpha\right)^T Q^{-1}(h-G_\alpha z_\alpha)\right\}=\left(G_\alpha^T Q^{-1} G_\alpha\right)^{-1}\left(G_\alpha^T Q^{-1} h\right) \tag{4}$$

Assuming that the values of the TOA data are independent each other, the Q matrix in Eq.(4) is a diagonal matrix.

$$Q=diag\left\{\sigma_1^2,\sigma_2^2,\ldots,\sigma_M^2\right\} \tag{5}$$

Due to R is actually related to $\left(x_i,y_i,z_i\right)$, we use Q matrix to approximately replace covariance matrix of the error vector ψ will bring some errors. In order to obtain a more accurate terminal position estimation, Eq.(3) can be converted to Eq.(6) when the error of TOA data is small.

$$\begin{aligned} &\psi=2Bn+n\odot n\approx 2Bn \\ &B=diag\left\{R_1^0,R_2^0,\ldots,R_M^0\right\} \end{aligned} \tag{6}$$

where： R_j^0 is the actual distance between the terminal and the *j*-th base station; n is TOA measurement error based on distance (approximately obeying normal distribution).

In order to get the B matrix, the measured R_j can be substituted for R_j^0, and the first WLS estimate of z_α is $z_\alpha=(G_\alpha^T\Psi^{-1}G_\alpha)^{-1}(G_\alpha^T\Psi^{-1}h)$.The covariance matrix of the error is as follows:

$$\Psi'=E\left[\psi'\psi'^T\right]=4B'\operatorname{cov}(z_\alpha)B';B'=diag\left\{x_i^{\ 0},y_i^{\ 0},z_i^{\ 0},\frac{1}{2}\right\} \tag{7}$$

The WLS of $z_\alpha{}'$ is estimated to be $z_\alpha{}'=(G_\alpha{}'\Psi'^{-1}G_\alpha{}')^{-1}(G_\alpha{}'^T\Psi'^{-1}h')$.From the above analysis, the final result of the terminal location is as follow:

$$z_p=sign\left(\sqrt{z_\alpha{}'}\right) \tag{8}$$

Where: $sign(x)=\begin{cases} 1,x>0 \\ 0,x=0 \\ -1,x<0 \end{cases}$.

Since the improved TOA-based positioning algorithm has a large error according to the above, the regression analysis of the terminal position prediction value and the real value is performed by using the test set data, and the error model for predicting the calculated value and the real value is established, and finally the error model is given by the error model. The exact three-dimensional coordinates of the terminal location. In this sub-question, partial least squares regression analysis [5] is used to establish a regression model between the first calculated value and the real value.

3. Simulation Results

Using the given test data set sample_case001_input_sample_case001_input, the regression relationship between the terminal position coordinates and the first-step calculated coordinate values is determined by partial least squares. The figure1 shows the terminal position coordinate regression prediction fit map.

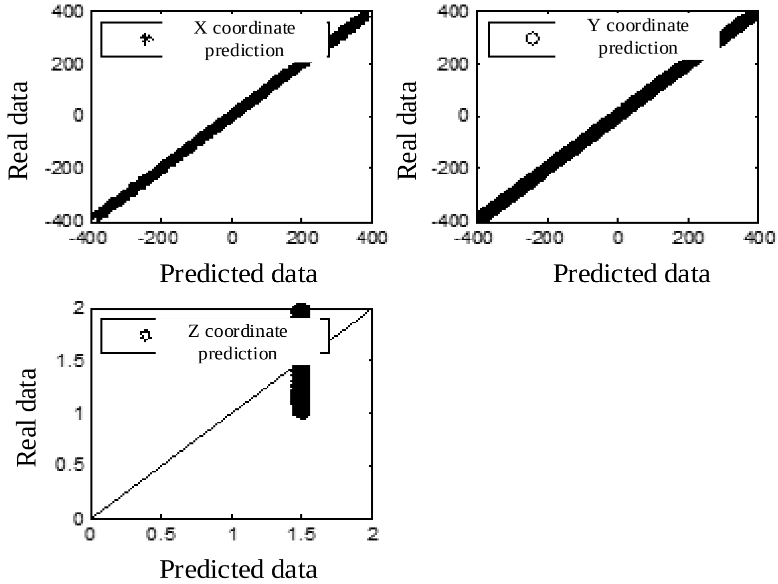

Figure 1. Test data set terminal position coordinate regression analysis

From $\text{beat3}=\begin{bmatrix}1.2688 & 0.3021 & 1.4897\\ 0.9538 & 0.0020 & -0.0000\\ 0.0020 & 0.9508 & 0.0000\\ 0.0044 & 0.6060 & 0.0221\end{bmatrix}$, we obtains that

$$\begin{aligned} x_i &= 1.2668 + 0.9583x_{0i} + 0.002y_{0i} + 0.0044z_{0i} \\ y_i &= 0.3021 + 0.002x_{0i} + 0.9508y_{0i} + 0.6060z_{0i} \\ z_i &= 1.4897 + 0.0221z_{0i} \end{aligned} \tag{9}$$

Finally, the exact three-dimensional coordinates of case001_input.txt to case010_input.txt are obtained by (9). The error map of case001_input.txt data set is as follows:

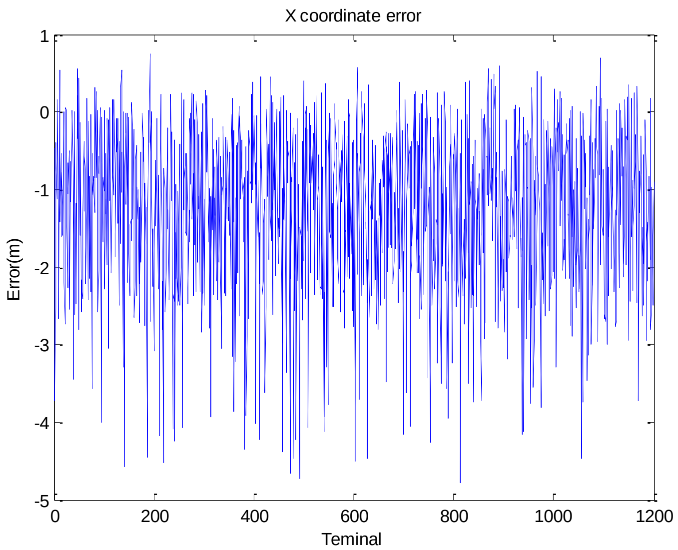

Figure 2. X coordinate error

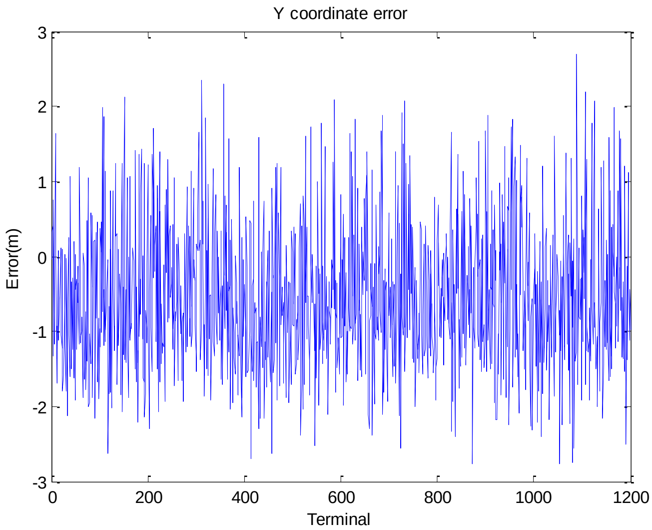

Figure 3. Y coordinate error

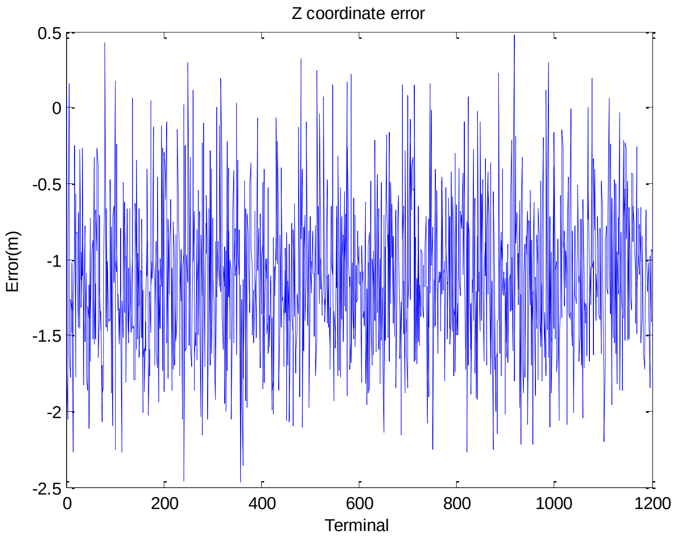

Figure 4. Z coordinate error

4. Conclusion

Due to limited information, the model still has room for improvement in practical applications. If the information is sufficient, in order to make the model more practical, it can be improved in the following two aspects:

(1) Filtering and reconstructing the initially measured TOA data, so that the interference of the NLOS error to the positioning is significantly reduced.

(2) The use of as few base stations as possible to complete the positioning of the terminal equipment, the fast convergence of the algorithm [6], and the robustness to interference and noise are the directions for further research and improvement in the future.

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