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Study of UWB Precise Positioning Problem under Signal Interference Conditions Based on Nonlinear Optimization Model

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Abstract: Taking the 2021 Huawei Cup E question as an example, for the analysis of the data collected in the experimental scenario 1 with or without signal interference, firstly, the corresponding values of each data file were captured using python tools and transformed into Excel data format, followed by data pre-processing according to different time stamps, inconsistent range values and calibration values, and repeated screening conditions for sequence numbers and numbers, and then using the Then the normal distribution 3σ principle was used to screen out the samples with abnormal range from the target point to the anchor point, and it was found that the range value given in the title deviated greatly from the actual point's range value in the process. Then, using the processed data, when the real coordinates of the target point are known, the particle swarm algorithm is used to solve the search for the global optimal distance from the target point to the four anchor points, and then the optimal distance is used to establish a nonlinear optimization model for four-point positioning in three-dimensional space, and the particle swarm algorithm is continued to be used to solve for the exact coordinates and error value range of the 324 Tag under no interference and with interference, and the error range can be used to predict The exact position of the control target point. Finally, the algorithm model is applied to calculate the coordinates of 10 sets of data, and then the two error values are corrected to get 10 sets of accurate values.

Keywords: UWB Precise Positioning; Nonlinear Optimization Model; Particle Swarm Algorithm.

1. Introduction

UWB (Ultra-Wideband) technology, also known as "Ultra-Wideband", is also known as pulse radio technology [1]. It is a wireless communication technology that transmits data over short distances by sending nanosecond pulses without any carrier, and the power consumption during signal transmission is only a few tens of μW [1]. UWB has a wide range of applications in various fields such as military and Internet of Things because of its unique characteristics. Among them, UWB-based positioning technology has real-time indoor and outdoor precise tracking capability and high positioning accuracy, which can reach centimeter-level or even millimeter-level positioning [2]. UWB's accurate positioning indoors will play an excellent complementary role to satellite navigation and can be widely used in military and civilian fields, such as: electric power, medical, chemical industry, tunnel construction, hazardous area control, etc [3].

There are various methods of UWB localization techniques, and in this paper, we only consider the Time of Flight (TOF) based ranging principle, which is one of the most common localization methods in UWB localization method [4]. TOF ranging technique is a two-way ranging technique, which calculates the time of flight of the signal in two modules and then multiplies it by the speed of light to find out the distance between two modules, and this distance definitely has different degrees of error, but its accuracy has been relatively high [5].

In indoor positioning applications, UWB technology can achieve centimeter-level positioning accuracy (generally refers to 2-dimensional planar positioning), and has good resistance to multipath interference and fading as well as strong penetration capability. However, due to the complex and variable indoor environment, UWB communication signals are highly susceptible to occlusion. Although UWB technology has penetration capability, it still generates errors, and in case of strong interference, abnormal data fluctuations (usually time delay) will occur, which basically makes indoor positioning impossible and can even cause serious accidents. Therefore, the problem of accurate positioning of ultra-wideband (UWB) under signal interference has become an urgent problem.

2. Experimental methods

To solve the problem of accurate positioning of ultra-wideband (UWB) under signal interference, we collected a certain amount of data by actual measurement of the actual scene, i.e., the distance between the anchor (anchor) and the target (Tag) using the localization technique of UWB (TOF).

2.1. Experimental scenarios and data acquisition

As shown in Figure 1, in a test environment of 5000mm*5000mm*3000mm, UWB anchors (anchor) are placed at 4 corners A0, A1, A2, A3 respectively, and the anchors send signals in all directions. tag is the UWB tag (target), i.e. the target to be located (only within the test environment). tag receives signals from 4 UWB anchors (anchor) (regardless of signal interference, tag can generally solve the corresponding 4 distance data). The Tag receives signals from four UWB anchors (anchor) (Tag can generally receive signals regardless of signal interference) and uses TOF technology to solve the corresponding four distance data respectively.

Experiments in experimental scenario 1 collected Tag in 324 different locations, in the signal without interference and signal interference UWB data, that is, each location each test (acquisition) 2 times, one signal without interference, the other signal with interference (between the anchor point and the target point is obscured), note: each time the data collection, because Tag in the same location will stay for a while time, and the anchor point and Tag between every 0.2 - Therefore, at the same location, UWB will collect multiple groups of data (multiple groups of data represent the information of the same location), the number of groups depends on the time of Tag in the same location, the longer the time of stay, the more the number of groups.

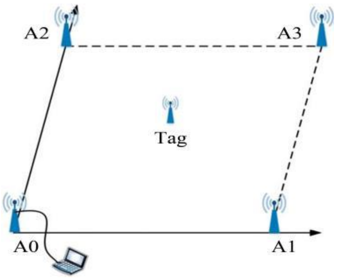

Fig 1. Schematic diagram of the actual measurement

Experimental scenario 1.
Target point (Tag) range: 5000mm*5000mm*3000mm
Anchor point (anchor) position (unit: mm)
A0 (0, 0, 1300), A1 (5000, 0, 1700),
A2 (0, 5000, 1700), A3 (5000, 5000, 1300

2.2. Data file description

1)UWB dataset

The "UWB data set" has 2 folders and 1 file. 1 file (Tag coordinate information.txt) holds the number and 3-dimensional coordinate information of 324 different locations, and 1 of the 2 folders holds the data collected under the signal without interference (normal) (each file is named x.normal.txt, x indicates the corresponding location number), and the other holds the data collected under the signal with interference (abnormal) (each file is named x.abnormal.txt, x indicates the corresponding location number). (x.normal.txt, x indicates the corresponding position number), and the other one stores the data collected under signal interference (abnormal) (each file name is x.abnormal.txt, x indicates the corresponding position number).

2)Data files

Tag collected 2 data files at each location (1 normal, the other 1 abnormal), a total of 648 data files, regardless of normal, abnormal data, the data format is the same, the first line at the beginning of each data file collection start line, no practical significance, followed by a group of every 4 lines, indicating a complete set of data collected by the UWB (a set of data indicates a sample), such as:

T:144235622: RR: 0:0:950: 950:118:1910
T:144235622: RR: 0:1:2630: 2630:118:1910
T:144235622: RR: 0:2:5120: 5120:118:1910
T:144235622: RR: 0:3:5770: 5770:118:1910

The meaning of these 4 rows of data are:

Tag identification: Timestamp: abbreviation for Range Report: Tag ID: anchor point ID: distance value (mm) of this anchor point: check value of the distance value: data sequence number: data number (separated by ":" between each data). It is actually the distance from the 4 anchor points to the target point (Tag) provided, i.e.

The distance from A0 to the target point is: 950mm
The distance from A1 to the target point is: 2630mm
The distance from A2 to the target point is: 5120mm
The distance from A3 to the target point is: 5770mm

Each data file has multiple sets of data, representing multiple sets of data automatically collected by the UWB at the same location over a continuous period of time

3. Data pre-processing (cleaning)

Whether the data is collected without signal interference or with signal interference, Tag collects multiple sets of data at the same coordinate point, and uses python tools to capture the corresponding values from each data file and convert them into two-dimensional table form, with each row representing a set of data (i.e., a sample), and then pre-processes (cleanses) these data files to remove some "useless" (abnormal, missing, identical or similar) data (samples).

3.1. Data scraping with python

The numpy library pd.read_concatcsv() function of python was used to manipulate the corresponding text files of "normal data" and "abnormal data" and save them as Excel data format. In order to make the results of the Excel table clear, every 4 rows are merged as a set of data, and through observation and analysis, four columns of Tag identification are merged into one column, four columns of Range Report are merged into one column, and four columns of Tag ID are merged into one column.

3.2. Data pre-processing

It was observed that the timestamps in the data files were different, the checksum values were used to check the range values, and the serial numbers and numbers were duplicated, so the filtering conditions were set to inconsistent timestamps, four range values and the corresponding checksum values were not equal, and the serial numbers and numbers were duplicated, as well as 3σ. If the filtering conditions were met, the data was considered "useless" and the group was deleted.

4. Data Modeling

4.1. Found errors

By data pre-processing. The actual coordinates of target point 2 were substituted into the two-point distance formula, and the distances from anchor points A0, A1, A2, and A3 to target point 2 were 1217 mm, 5206 mm, 5158 mm, and 7069 mm. Then the measured distance values of the second target point of normal data were analyzed correspondingly, which showed that the measured distance values of anchor points had some errors.

4.2. Building optimization models and solving them

4.2.1. Coordinate operations

The locations of the four UWB anchor points A0, A1, A2, and A3 in Experimental Scenario 1 are known to be A0 (0, 0, 1300), A1 (5000, 0, 1700), A2 (0, 5000, 1700), and A3 (5000, 5000, 1300), respectively.

Suppose the position of the target point is x_i, y_i, z_i, for the anchor points A0, A1, A2, A3 satisfy the system of equations.

$$\begin{cases} x^2+y^2+(z-1300)^2=d_0{}^2 \\ (x-5000)^2+y^2+(z-1700)^2=d_1{}^2 \\ x^2+(y-5000)^2+(z-1700)^2=d_2{}^2 \\ (x-5000)^2+(y-5000)^2+(z-1300)^2=d_3{}^2 \end{cases}$$

Eliminating all the quadratic terms of the above system of nonlinear equations thus gives.

$$\begin{pmatrix} -10000 & 0 & -800 \\ 0 & -10000 & -800 \\ -10000 & -10000 & 0 \end{pmatrix}\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} d_1^2 - d_0^2 - 26200000 \\ d_2^2 - d_0^2 - 26200000 \\ d_3^2 - d_0^2 - 50000000 \end{pmatrix}$$

At this point, the above equation becomes in the form AX = B. According to the linear algebraic method, $X = A^{-1}B$, i.e., the solution of the system of equations can be obtained by simply inverting the coefficient matrix and multiplying it by the constant matrix, i.e., the corresponding coordinates.

4.2.2. Optimization model building

1) Under interference-free conditions:

Suppose the experimental scene 1 is the scene area D, $D_1 = X \times Y \times Z$. Which X ∈ (0, 5000), Y ∈ (0, 5000), Z ∈ (0, 3000), let the real target point coordinates be $T_1, T_2 \cdots T_n$, which $T_1, T_2 \cdots T_n \in D$ .Positioning model for normal data:

$$min\left(\sum_{j=1}^{m}(A_0T_i - A_0T_{ij})^2 + \sum_{j=1}^{m}(A_1T_i - A_1T_{ij})^2 + \sum_{j=1}^{m}(A_2T_i - A_2T_{ij})^2 + \sum_{j=1}^{m}(A_3T_i - A_3T_{ij})^2\right)$$

$$s.t\begin{cases} \sqrt{\sum_{i=0}^{3}\left(x_i^T - x_{AK}\right)^2} \\ Ax_i^T = b \\ x_i^T \in D_1 \end{cases}$$

The model solves the coordinates of the 324 target points in the normal data as follows:

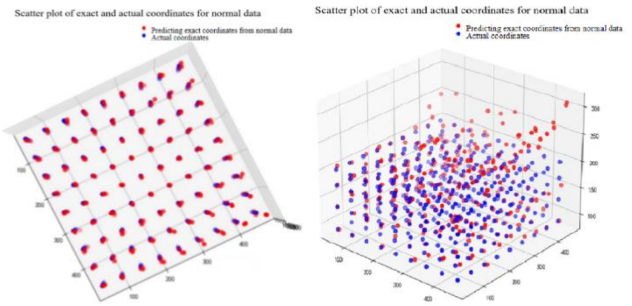

Figure 2. Scatter plot of normal data prediction results

The 324 exact coordinates of the calculated normal data and the actual coordinates of the target point (x_0, y_0, z_0), Perform solving error $(\omega_x, \omega_y, \omega_z)$:

$$\omega_x = \sqrt{\sum_{i=1}^{324}(x_i - x_0)^2 / 324}$$

$$\omega_y = \sqrt{\sum_{i=1}^{324}(y_i - y_0)^2 / 324}$$

$$\omega_z = \sqrt{\sum_{i=1}^{324}(z_i - z_0)^2 / 324}$$

the results of the error calculation under the condition of no interference are shown in Table 1:

Table 1. Errors under interference-free conditions

ω_x	ω_y	ω_z
0.18695145	0.171233722	1.733724597

2) with interference conditions:

First, the range value of the abnormal data is corrected, and the range value of the normal data is used as the output, and the range value of the abnormal data is used as the output, and the correlation between the abnormal data and the normal data is trained by the BP neural prediction model, and then the range value of the abnormal data is used as the input to derive the corrected range value with the range value of the normal data as the standard $\hat{x}_i$.

$$min\left(\sum_{j=1}^{m}(A_0T_i - A_0T_{ij})^2 + \sum_{j=1}^{m}(A_1T_i - A_1T_{ij})^2 + \sum_{j=1}^{m}(A_2T_i - A_2T_{ij})^2 + \sum_{j=1}^{m}(A_3T_i - A_3T_{ij})^2\right)$$

$$s.t\begin{cases} \sqrt{\sum_{i=0}^{3}\left(\hat{x}_i^T - x_{AK}\right)^2} \\ A\hat{x}_i^T = b \\ \hat{x}_i^T \in D_1 \end{cases}$$

The corrected range values are then brought into the optimized calculation model to derive the exact coordinates of the 324 anomalous (with interference) target points. The results of the model solving for the coordinates of the 324 targets in the anomalous data are shown in Figure 3:

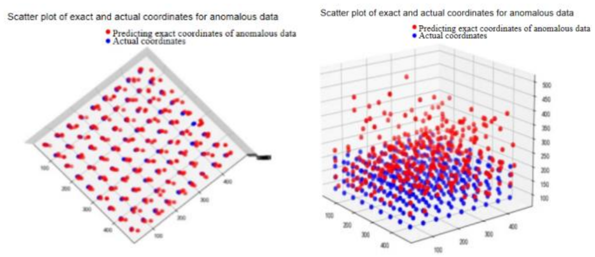

Figure 3. Scatter plot of anomaly data prediction results

with the actual coordinates of the target (x_0, y_0, z_0), Perform solving error (W_x, W_y, W_z):

$$W_x = \sqrt{\sum_{i=1}^{324}(x_i - x_0)^2 / 324}$$

$$W_y = \sqrt{\sum_{i=1}^{324}(y_i - y_0)^2 / 324}$$

$$W_z = \sqrt{\sum_{i=1}^{324}(z_i - z_0)^2 / 324}$$

That is, the results of the error calculation under the condition of interference are shown in Table 2:

Table 2. Errors under interference-free conditions

W_x	W_y	W_z W_z
0.531527722	0.505909296	5.934959678

4.2.3. Locating the given data

The coordinates of the 5 sets of normal data in the attachment are first solved by the above-mentioned calculation model$(\omega_x, \omega_y, \omega_z)$, and then the coordinates are corrected with the normal error values to obtain the exact coordinates, the same for the 5 groups of outliers and the results are shown in Table 3:

Table 3. Exact coordinates of the 10 sets of data

Groups	x	y	z
Date 1	147±0.1869 5145	254±0.1712 33722	213±1.733724597
Date 2	244±0.1869 5145	100±0.1712 33722	227±1.733724597
Date 3	273±0.1869 5145	116±0.1712 33722	80±1.733724597
Date 4	317±0.1869 5145	171±0.1712 33722	76±1.733724597
Date 5	117±0.1869 5145	67±0.17123 3722	69±1.733724597
Date 6	489±0.5315 27722	198±0.5059 09296	-96±5.934959678
Date 7	355±0.5315 27722	200±0.5059 09296	267±5.934959678
Date 8	177±0.5315 27722	127±0.5059 09296	270±5.934959678
Date 9	432±0.5315 27722	158±0.5059 09296	-75±5.934959678
Date 10	209±0.5315 27722	72±0.50590 9296	-20±5.934959678

5. Conclusion

In the experimental scenario 1, we analyzed the data collected with and without signal interference by studying the problem of ultra-wideband (UWB) precise positioning under signal interference. Firstly, we use python tool to capture the data, secondly, we pre-process the data file to remove some "useless" data to reduce the interference, and in this process, we find that the range value given in the question deviates from the actual point's range value. Finally, under the condition that the real coordinates of the target point are known, the particle swarm algorithm is used to solve the search for the global optimal distance from any target point to the four anchor points, and then the nonlinear optimization model of four-point localization in three-dimensional space without and with interference is established by using the optimal distance, in order to reflect the accurate position of the Tag more accurately.

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