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Article

Positioning method of weighted centroid aided inertial measurement

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Abstract: Aiming at the defects of low precision and time cumulative error, an external wireless signal weighted centroid localization algorithm aided inertial positioning method is designed in this paper. According to the signal strength of each anchor node received at the test point, the distance between the anchor node and the anchor node is obtained by using the attenuation model of the wireless signal. Three anchor nodes are used to measure the distance between the anchor node and the measured point. We can obtain the area to be measured according to the actual situation, the position of the measured point is obtained by the weighted centroid localization algorithm and a combined model of wireless signal aided inertial navigation system is established. The simulation results show that the method can greatly improve the positioning accuracy and restrain the divergence of the longitude error and latitude error.

Keywords: weighted centroid; signal intensity; attenuation model; combined model

1. Introduction

Due to the development of the Internet and the popularity of mobile devices and personal devices, LBS (Based Services Location) is becoming increasingly important, users get positioning information [1] and use it for navigation, tracking, monitoring, pushing information and other services. GPS can easily provide outdoor personal location information, but because the GPS needs to receive at least 4 satellites to achieve positioning. Therefore, the influence of the satellite signal has a great influence on the positioning effect, and it has a serious impact on the positioning effect in the indoor environment due to the occlusion of the satellite signal.

Inertial navigation system has the advantages of strong autonomy, high output frequency, short time accuracy, especially the rapid development of MEMS IMU in recent years makes it become small and the cost is lower. It often uses the Pedestrian Dead Reckoning method with MEMS IMU for Indoor positioning. At present, most of the Pedestrian Dead Reckoning methods are to fix the inertial sensor on the human torso [2] or foot [3]. The lack of flexibility of this approach has greatly affected the user experience. Zero Velocity Update Colman filtering algorithm [4] can limit the error in the range of linear growth, it can also help Colman filter to eliminate the accumulated error of inertial navigation direction with gyroscopes, electronic compass and magnetic measurement meter value [5]. To a certain extent, this method improves the precision of navigation, but it will produce a certain cumulative error with the increase of time.

Wireless positioning has been widely used due to the popularity of Wi-Fi hotspots, wireless sensor networks, Bluetooth and other wireless signals. In order to solve the problem of long time accumulation of inertial positioning errors, this paper uses the wireless signal weighted centroid algorithm to assist the inertial positioning, and derive the state equation and the measurement equation in detail. Colman filter is used to estimate the optimal combination system, and simulate the effect of the combination. The simulation results show that the combined system can restrain the divergence of the error, and greatly improve the positioning accuracy. At the same time, it is compared with the traditional centroid location algorithm aided inertial positioning. The results show that the auxiliary effect of the weighted centroid localization is better, and the positioning accuracy is higher.

2. Weighted centroid localization method for wireless signals

Some methods are commonly used to measure the distance between nodes, such as RSSI (Received Signal Strength Indicator) [6], TOA (Time of Arrival), TDOA (Time Difference of Arrival), AOA (Angel of Arrival) and other positioning algorithms.

TOA and TDOA introduce the concept of time and add additional hardware requirements. AOA positioning error is relatively large. The localization algorithm based on RSSI is easy to implement and does not require additional hardware overhead. But RSSI positioning algorithm signal is vulnerable to the impact of the environment in the propagation process, such as reflection, diffraction, nonvisual range, etc. In order to solve this problem, this paper uses the method of adjusting the signal transmission factor to adjust the model parameters of the path loss dynamically, so as to reduce the positioning error. The distance between the measured point and the anchor node is measured according to the wireless signal, so as to determine the area where the measurement point is located, and further the position of the measured point is obtained according to the weighted centroid localization algorithm.

2.1. Basic principle of signal strength ranging

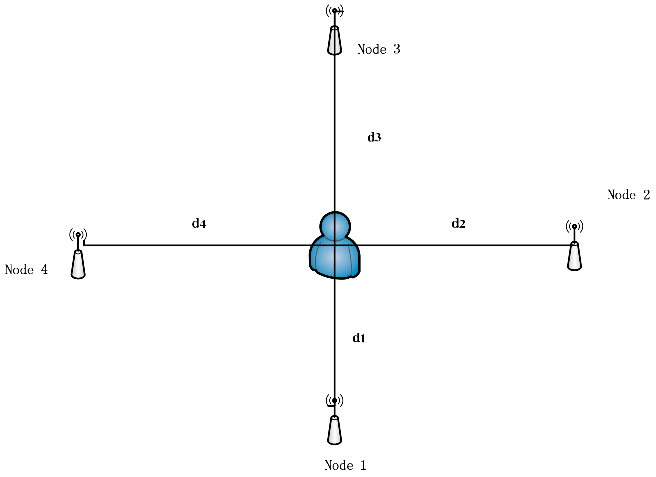


Figure 1. Wireless Location Network Structure

RSSI ranging is very easy to be affected by the environment, therefore, how to further improve the range accuracy is the key to ranging technology [7]. The research shows that the transmission loss can be converted to a distance by using the propagation loss model, which is known to be the power of the transmitting node and the receiving node, the traditional wireless signal attenuation model is:

$$\boldsymbol{RSSI}(\boldsymbol{d}) = \boldsymbol{RSSI}(\boldsymbol{d}_0) - 10\boldsymbol{n}\lg(\boldsymbol{d}/\boldsymbol{d}_0) + \varsigma_\sigma \tag{1}$$

Where $\boldsymbol{RSSI}(\boldsymbol{d})$ indicates the received signal strength value, which goes to launch anchor nodes at a distance of $\boldsymbol{d}$. $\boldsymbol{RSSI}(\boldsymbol{d}_0)$ indicates the received signal strength value, which goes to launch anchor nodes at a distance of $\boldsymbol{d}_0$. $\boldsymbol{d}_0$ is generally used as the reference distance. Because the distance is farther, the attenuation is more serious, so we generally select the distance from the launch anchor node closer. Generally set it to 1m. $\boldsymbol{n}$ represents path attenuation factor(range between 2 and 4). ς_σ represents normal random variable and σ represents standard deviation.

When $\boldsymbol{d}_0$ is 1, equation (1) can be converted to:

$$\boldsymbol{RSSI}(\boldsymbol{d}) = \boldsymbol{RSSI}(1) - 10\boldsymbol{n}\lg(\boldsymbol{d}) + \varsigma_{\sigma} \tag{2}$$

Because the traditional signal model has the disadvantage of being influenced by the environment easily. In this paper, we use the method of adjusting the model factor to improve the signal attenuation model. Select three anchor nodes randomly in Figure 1. Assuming that the selected anchor node is 1, 2, 3, and 1 is anchor node, 2 and 3 are points to be located. Assuming that is 1, according to the signal attenuation model, we can get:

$$\boldsymbol{RSSI}(\boldsymbol{d}_{12}) = \boldsymbol{RSSI}(1) + 10\boldsymbol{n}_1\lg(\boldsymbol{d}_{12}) + (\varsigma_{\sigma})_1 \tag{3}$$

$$\boldsymbol{RSSI}(\boldsymbol{d}_{13}) = \boldsymbol{RSSI}(1) + 10\boldsymbol{n}_1\lg(\boldsymbol{d}_{13}) + (\varsigma_{\sigma})_1 \tag{4}$$

Assuming that $\lambda_1 = \boldsymbol{RSSI}(1) + (\varsigma_{\sigma})$, and we can get propagation parameters λ_1 and $\boldsymbol{n}_1$ of anchor node 1, from equation (3) and equation (4).

Usually, there will be an anchor node nearest to the anchor node in the large number of anchor nodes. Because the closer to the anchor node, the less affected by the environment, then the anchor node is the optimal anchor node. Therefore, the parameter adjustment factor is introduced:

$$\boldsymbol{e}_i = \frac{\boldsymbol{RSSI}(\boldsymbol{d}_i) - \boldsymbol{RSSI}(\boldsymbol{d}_1)}{\sum_{i=2}^{\boldsymbol{n}}[\boldsymbol{RSSI}(\boldsymbol{d}_i) - \boldsymbol{RSSI}(\boldsymbol{d}_1)]} \tag{5}$$

Where $\boldsymbol{n}$ is number of anchor nodes, $\boldsymbol{d}_1$ is the distance between the optimal anchor node and the location node, $\boldsymbol{RSSI}(\boldsymbol{d}_i)$ is the signal strength of the i(i=1, 2, 3..) node received by the anchor node.

Then the adjustment model propagation parameters are:

$$\lambda = \sum_{i=1}^{\boldsymbol{n}} \frac{1 - \boldsymbol{e}_i}{\boldsymbol{n} - 1} \times \lambda_i \tag{6}$$

$$\boldsymbol{n} = \sum_{i=1}^{\boldsymbol{n}} \frac{1 - \boldsymbol{e}_i}{\boldsymbol{n} - 1} \times \boldsymbol{n}_i \tag{7}$$

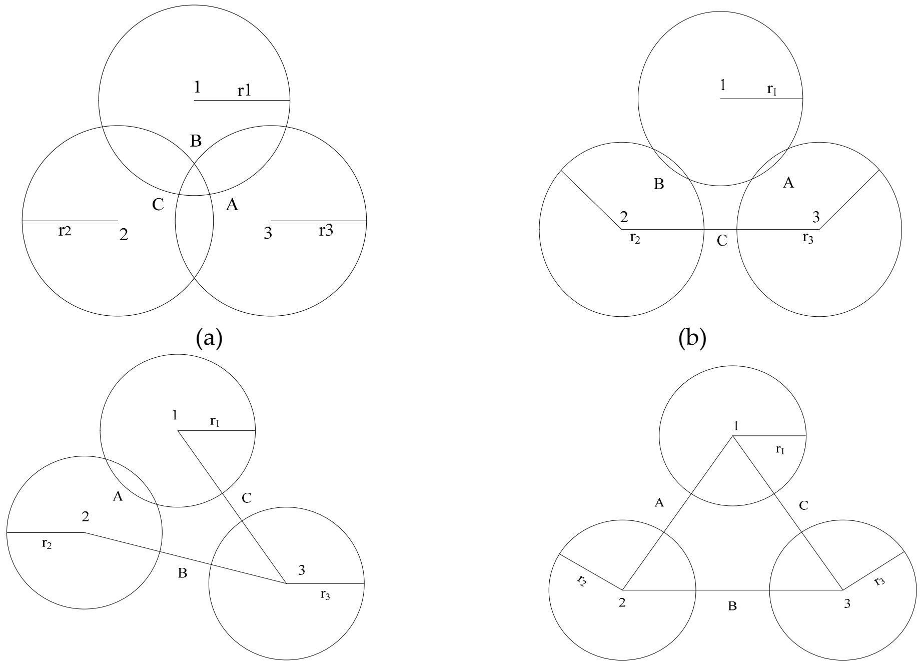
The adjustment factor is introduced to make the propagation parameters of the nodes close to the positioning node get better. The propagation path loss model is:

$$\boldsymbol{RSSI}(\boldsymbol{d}) = \lambda + 10\boldsymbol{n}\lg(\boldsymbol{d}) \tag{8}$$

Before wireless location, we should get the propagation parameters $\boldsymbol{\lambda}$, $\boldsymbol{n}$, $\boldsymbol{e}$ of the corresponding propagation environment. Therefore, it can improve the accuracy of the propagation loss model, so as to improve the accuracy of wireless location.

2.2. Weighted centroid localization algorithm

The signal intensity of the transmitting node and the transmitting node are known, RSSI can calculate the propagation loss of the signal according to the signal strength received by the receiving node. Then the propagation loss is transformed to the distance by using the theory and empirical model, and the position of the node is calculated according to the distance [8]. In theory, circles are drawn based on the distance from the propagation loss model at each anchor node, and these circles intersect at a point. This is the point of theory to be located, but in the actual situation all circles do not intersect at one point, Choose 1, 2, 3 node as an example, the actual situation may be the following:



(a) (b)

(c) (d)

Figure 2. Wireless Location of The Actual Situation

Take two equations randomly and go simultaneous, and the intersection point of the two circle is obtained. When two circles have two points of intersection, choose the point closer to the third circle, which is outside the two circles. If two circles have no intersection, then take the midpoint of the connecting line of the center, so we get three points A, B, C, as shown in Figure 2. And the unknown point must be in the region of A, B, and C. Obviously, with the increase of the number of the communication anchor nodes, the possible area of the unknown node is gradually reduced [9]. Take Figure 2 (a) as an example, the centroid of A, B, C is used as the position of the unknown point:

$$x = (x_A + x_B + x_C)/3 \tag{9}$$

$$y = (y_A + y_B + y_C)/3 \tag{10}$$

Because the coordinate of the unknown point is located through the A, B, C points, traditional centroid localization algorithm does not consider A, B, C to the extent of the impact of the unknown point, so the traditional centroid localization algorithm has a certain error in positioning. In this paper, a weighted method is used to reflect the contribution of different vertices to the unknown point. The farther away from the anchor node, the smaller the proportion of the corresponding node coordinates, which is inversely proportional to the distance, each vertex is determined by two distances. As is shown in Figure 2 (a), A point is determined by circle 1 and circle 2, then the weight of the corresponding A point should be $1/(r_1 + r_2)$. Similarly, the weight of the B point is $1/(r_2 + r_3)$ and the weight of the C point is $1/(r_3 + r_1)$. Then the unknown point coordinates determined by weighted centroid localization algorithm are:

$$x = \frac{\dfrac{x_A}{r_1 + r_2} + \dfrac{x_B}{r_2 + r_3} + \dfrac{x_C}{r_3 + r_1}}{\dfrac{1}{r_1 + r_2} + \dfrac{1}{r_2 + r_3} + \dfrac{1}{r_3 + r_1}} \tag{11}$$

$$y = \frac{\dfrac{y_A}{r_1 + r_2} + \dfrac{y_B}{r_2 + r_3} + \dfrac{y_C}{r_3 + r_1}}{\dfrac{1}{r_1 + r_2} + \dfrac{1}{r_2 + r_3} + \dfrac{1}{r_3 + r_1}} \tag{12}$$

3. Wireless signal assisted SINS positioning principle

Due to the development of MEMS technology, now the mobile terminal used for positioning of the inertial sensors are mostly MEMS IMU, because the gyro drifts very large and the earth's rotation rate is very small, so the earth's rotation speed is completely submerged in noise. So it will be relatively large to calculate the heading error by using a gyroscope. Today, most of the MEMS IMU integrated magnetic meter, method for calculating heading angle by magnetic force meter has also been gradually got the research and application [10], this paper adopt the method of using magnetic force to assist MEMS IMU heading information. The principle block diagram of wireless signal aided SINS positioning as shown in Figure 3.

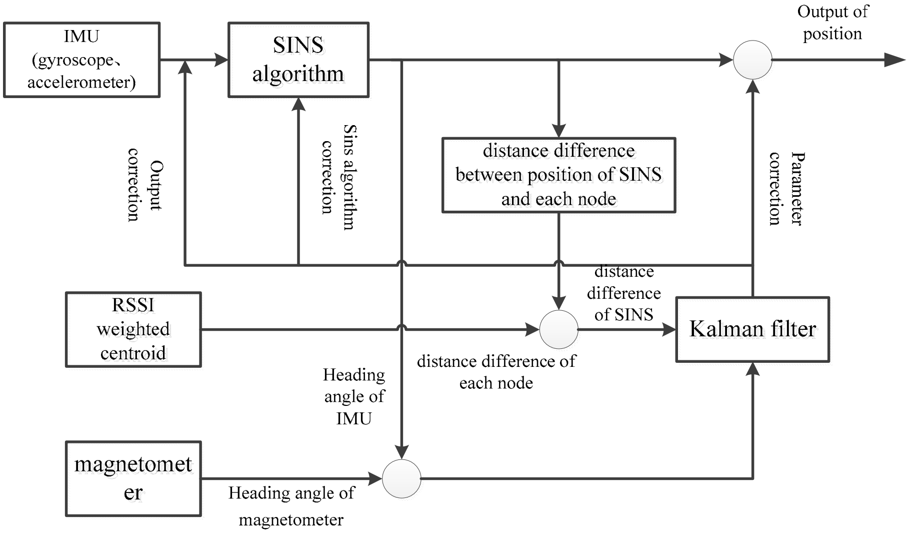


Figure 3. Principle of Wireless Signal Aided Inertial Positioning

3.1. State equation and measurement equation of RSSI weighted centroid localization aided inertia

The error state equation of SINS system is

$$\dot{X}_{SINS} = F_{SINS} X_{SINS} + G_{SINS} W_{SINS} \tag{13}$$

The state equation for wireless signal localization is:

$$\dot{X}_{RSSI} = F_{RSSI} X_{RSSI} + G_{RSSI} W_{RSSI} \tag{14}$$

Combine equation (13) and (14), then we can get the state equation of the system:

$$\begin{bmatrix} \dot{X}_{SINS} \\ \dot{X}_{RSSI} \end{bmatrix} = \begin{bmatrix} F_{SINS} & 0 \\ 0 & F_{RSSI} \end{bmatrix} \begin{bmatrix} X_{SINS} \\ X_{RSSI} \end{bmatrix} + \begin{bmatrix} G_{SINS} & 0 \\ 0 & G_{RSSI} \end{bmatrix} \begin{bmatrix} W_{SINS} \\ W_{RSSI} \end{bmatrix} \tag{15}$$

Where $\dot{X}_{SINS}$, $\dot{X}_{RSSI}$ represent state variable of SINS and wireless location respectively. $\boldsymbol{F_{SINS}}$, $\boldsymbol{F_{RSSI}}$ represent system transfer matrix of SINS and wireless location respectively. $\boldsymbol{G_{SINS}}$, $\boldsymbol{G_{RSSI}}$ represent process noise transfer matrix of SINS and wireless location respectively. $\boldsymbol{W_{SINS}}$, $\boldsymbol{W_{RSSI}}$ represent system noise of SINS and wireless location respectively.

$$X_{SINS} = [\delta V_E \;\; \delta V_N \;\; \delta V_U \;\; \varphi_E \;\; \varphi_N \;\; \varphi_U \;\; \delta_L \;\; \delta_\lambda \;\; \delta_h \;\; \nabla_{bx} \;\; \nabla_{by} \;\; \nabla_{bz} \;\; \varepsilon_{bx} \;\; \varepsilon_{by} \;\; \varepsilon_{bz}]^T \tag{16}$$

Where δV_E, δV_E, δV_E are eastward velocity error, north direction velocity error and the velocity error of the sky direction respectively. φ_E, φ_N, φ_U are east to the misalignment angle, north to the misalignment angle and the misalignment angle of the direction of the sky respectively. δ_L, δ_λ, δ_h are Latitude error, longitude error and height error respectively. ∇_{bx}, ∇_{by}, ∇_{bz} are three axial offset error of accelerometer. ε_{bx}, ε_{by}, ε_{bz} are three axial drift of gyroscope. $\boldsymbol{F}_{\boldsymbol{SINS}}$ can be determined by the SINS error equation.

$$\boldsymbol{X}_{\boldsymbol{RSSI}} = [\delta \boldsymbol{R}_1 \quad \delta \boldsymbol{R}_2 \quad \delta \boldsymbol{R}_3\ ]^T \tag{17}$$

RSSI aided inertial positioning calculates the position by inertia, and calculate the distance from each wireless node according to the position. According to the distance we can further get the distance difference, and it is measured as the measurement information with the distance difference calculated by the wireless signal. The measurement equation is described as:

$$\boldsymbol{Z} = \rho_{\boldsymbol{SINS}} - \rho_{\boldsymbol{RSSI}} = \begin{bmatrix} \rho_{\boldsymbol{SINS}1} - \rho_{\boldsymbol{RSSI}1} \\ \rho_{\boldsymbol{SINS}2} - \rho_{\boldsymbol{RSSI}2} \\ \rho_{\boldsymbol{SINS}3} - \rho_{\boldsymbol{RSSI}3} \end{bmatrix} = \boldsymbol{HX} + \boldsymbol{V} \tag{18}$$

Assuming that the position of the SINS calculation is (x, y, z), then:

$$\begin{aligned} \rho_{\boldsymbol{SINSi}} &= \sqrt{(x_{\boldsymbol{SINS}} - x_i)^2 + (y_{\boldsymbol{SINS}} - y_i)^2 + (z_{\boldsymbol{SINS}} - z_i)^2} \\ &- \sqrt{(x_{\boldsymbol{SINS}} - x_0)^2 + (y_{\boldsymbol{SINS}} - y_0)^2 + (z_{\boldsymbol{SINS}} - z_0)^2} \end{aligned} \tag{19}$$

Assuming that the position of the wireless signal calculated by the weighted centroid location algorithm is, then

$$\begin{aligned} \rho_{\boldsymbol{RSSIi}} &= \sqrt{(x_{\boldsymbol{RSSI}} - x_i)^2 + (y_{\boldsymbol{RSSI}} - y_i)^2 + (z_{\boldsymbol{RSSI}} - z_i)^2} \\ &- \sqrt{(x_{\boldsymbol{RSSI}} - x_0)^2 + (y_{\boldsymbol{RSSI}} - y_0)^2 + (z_{\boldsymbol{RSSI}} - z_0)^2} \end{aligned} \tag{20}$$

Where $\boldsymbol{i}$ represents nodes except node 0.

3.2. State equation and measurement equation of SINS/ magnetometer

The equation of state for the SINS/magnetometer is

$$\begin{bmatrix} \dot{X}_{SINS} \\ \dot{X}_{\text{magnetometer}} \end{bmatrix} = \begin{bmatrix} F_{SINS} & 0 \\ 0 & F_{\text{magnetometer}} \end{bmatrix} \begin{bmatrix} X_{SINS} \\ X_{\text{magnetometer}} \end{bmatrix} + \begin{bmatrix} G_{SINS} & 0 \\ 0 & G_{\text{magnetometer}} \end{bmatrix} \begin{bmatrix} W_{SINS} \\ W_{\text{magnetometer}} \end{bmatrix} \tag{21}$$

The selection of SINS state quantity $\dot{X}$ and system transfer matrix are the same as 2.1. The error of heading angle is chosen as the state of

$$\boldsymbol{X}_{\text{magnetometer}} = \delta\psi_{\text{magnetometer}} \tag{22}$$

The measurement equation is:

$$\boldsymbol{Z} = \boldsymbol{H} \begin{bmatrix} \boldsymbol{X}_{\boldsymbol{SINS}} \\ \boldsymbol{X}_{\text{magnetometer}} \end{bmatrix} + \boldsymbol{V} \tag{23}$$

Where

$$\boldsymbol{Z} = \hat{\psi}_{\boldsymbol{SINS}} - \hat{\psi}_{\text{magnetometer}} \tag{24}$$

4. Simulation and analysis

4.1 Simulation condition setting

In order to verify the effect of the weighted centroid location aided inertial positioning of the wireless signal, the simulation experiment of 1500s is carried out by using C++. The simulation

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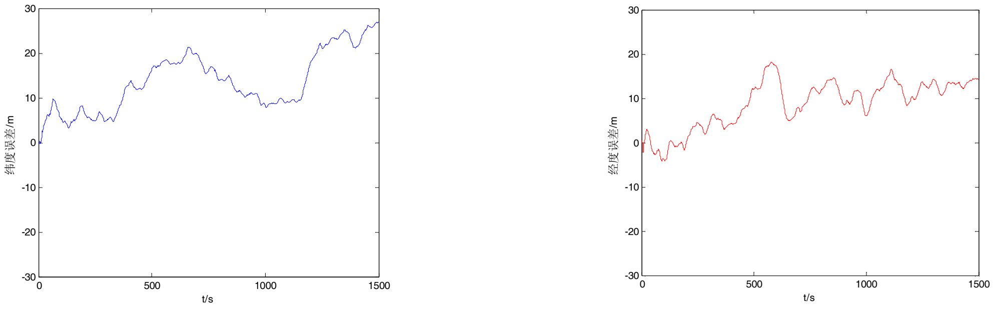
conditions are set as follows: gyro constant drift is 0.04°/h, gyro random drift is 0.04°/h, accelerometer zero bias is 100μg, accelerometer random bias is 50μg. The initial parameters of the carrier are as follows: pitching angle is, roll angle is 0°, heading angle is 0°, initial pitch angle error is 135°, initial roll angle error is 0.02°, and heading angle error is 0.02°. The initial position error is set as follows: latitude error is 1m, longitude error is 1m. The position of the four wireless nodes are as follows: node 1 (32°, 118.01°), node 2 (32.01°, 118.02°), node 3 (32.02°, 118.01°) and node 4 (32.01°, 118°). Set the carrier to travel at a constant speed, the speed is 1m/s, the starting position is (32°, 118°), then carry out the simulation experiment of 1500s.

4.2 Simulation results and analysis

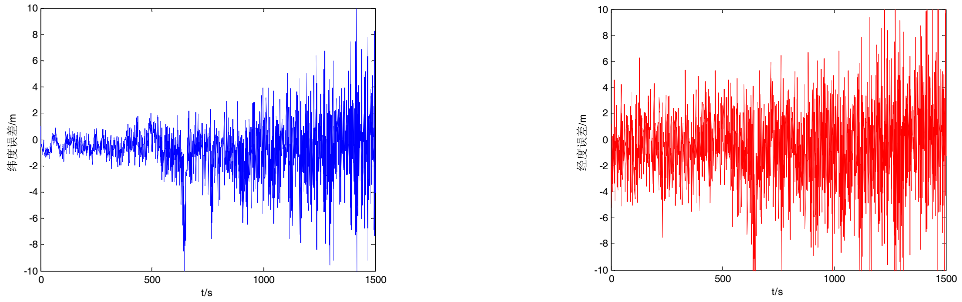
Based on the simulation conditions, we can obtain the simulation results of SINS without auxiliary and wireless assistant. Because it is mainly to study the positioning effect, it is important to study the information of longitude and latitude. Figure 4 is the traditional centroid algorithm assisted SINS's latitude and longitude error in the traditional transmission model of wireless signal, it can be seen from the figure that the error of SINS can be restrained, and it is gradually spread into convergence, but the errors on the way show great fluctuation. This is mainly due to the traditional communication model itself vulnerable to the impact of the environment, which brings greater errors. On the other hand, because the position of the measured point is only determined by the centroid algorithm, when the measured point is located near the center of mass of the defined area, there is a high precision, but when the measured point is in the boundary position of the defined area, the error will be relatively large. Figure 6 is the latitude and longitude error of the auxiliary SINS of the weighted centroid location algorithm, which is based on the signal propagation model in this paper. This algorithm can restrain the divergence of SINS error very well and compared to the algorithm in Figure 5, this method introduces the weight value to determine the position of the measured point, and the high precision can be obtained when the measured point falls into the boundary.

The algorithm can reduce the error of latitude and longitude and greatly improve the auxiliary effect of wireless signal assistant SINS; Table 1 is the simulation results.



(a) (b)

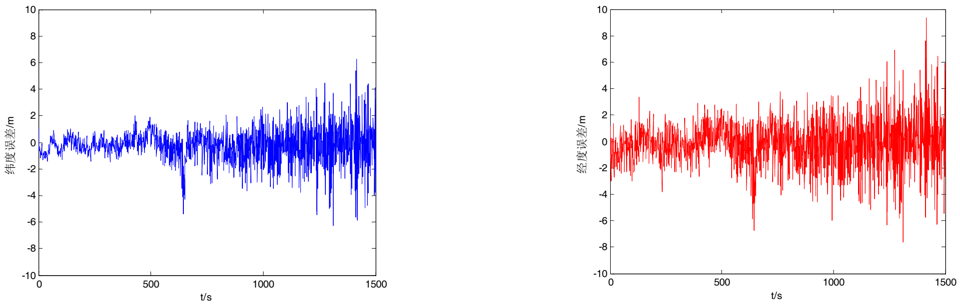
Figure 4. The latitude and longitude error of pure SINS location. (a) Latitude error; (b) Longitude error.



(a) (b)

Figure 5. The error of latitude and longitude in the traditional propagation model assisted SINS.

(a) Latitude error; (b) Longitude error.



(a) (b)

Figure 6. The auxiliary SINS location error of latitude and longitude in the propagation model in this paper. (a) Latitude error; (b) Longitude error.

Table 1. Comparison of simulation results of three kinds of positioning

	Latitude average deviation (m)	**Longitude average deviation (m)**	**Maximum deviation of latitude (m)**	**Maximum deviation of longitude (m)**	**Standard deviation of latitude (m)**	**Standard deviation of longitude (m)**
Single SINS	13.5977	9.1389	26.9316	18.2245	6.5798	7.2239
Traditional method	1.6007	2.6412	10.8778	16.9741	2.1908	3.4389
Method in this paper	0.9511	1.3758	6.3075	9.3784	1.3024	1.8247

By comparing Figure 4 , Figure 5 , Figure 6 and Table 1, we can see that: the weighted centroid localization algorithm based on the signal propagation model can effectively restrain the divergence of the SINS positioning error, and the steady-state error is smaller compared to the traditional method.

By analyzing the standard deviation of latitude and longitude, it can be seen that the stability is more stable in this paper.

5. Conclusions

Aiming at the defects of low positioning accuracy for MEMS IMU and time cumulative error, we use the wireless signal aided inertial algorithm in this paper, which is widely used to improve the positioning accuracy. By selecting the optimal anchor node, then calculate the adjustment factor, and adjust the propagation model coefficient. By the position of the initial fixed point of each anchor node, the method of weighted centroid is used to find the location of the measured point. Finally, a model of wireless signal assisted SINS is established. The results show that the method can effectively restrain the divergence of SINS, and improve the steady-state accuracy and positioning stability compared to the traditional method.

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Author Contributions: Q.L. designed the system structure and experiments, wrote the paper. X.X. performed the simulation. T.Z. wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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