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A Trilaminar Data Fusion Localization Algorithm Supported by Sensor Network

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Abstract: In order to overcome some problems, such as its low accuracy and failure in evaluating its performance, this paper use the weighted trilaminar data fusion of LS-RSSI to improve the incipient localization estimate values by analyze and study the lease square (LS) and Received Signal Strength Indication (RSSI) algorithm. As a result, we obtain a trilaminar data fusion localization algorithm of LS-RSSI, which has a better optimized localization estimate value. This algorithm has the advantages of limited numbers of calculation and is able to reduce the localization errors. As shown in the simulation, we are able to get a much more accuracy and stable localization estimate value with the trilaminar data fusion technology. *Copyright © 2013 IFSA.*

Keywords: Trilaminar data fusion, LS, Data weighted, RSSI.

1. Introduction

With the development in communication technology, embedded computer technology and microchip technology, wireless sensor networks (WSN) get a rapid advancement and it is widely used in military, manufacturing industry and life care [1, 2]. In recent years, wireless localization technology has become one of the major technologies in wireless communication. For many users, the localization data obtained from the transducer integrated by localization unit will make practical sense.

The wireless localization technology can be divided into range-free based localization and range based localization according to whether it measures the distance during the locating [3]. There is no need to measure the absolute distance and angle information between the nodes in range-free localization algorithm, but the range based localization algorithm needs to be calculated the distance with the connectivity of the network. Considering the cost, the range-free based localization technology is more suitable for WSN as it does not need much hardware support. There are some range based localizations, such as Angle of Arrival (AOA) [4, 5], Time of Arrival (TOA) [6, 7], Time Different of Arrival (TDOA) [8], and Received Signal Strength Indication (RSSI) [9-11]. Since the environment of wireless communication has become increasingly complex, the unitary localization algorithm is not able to meet the localization accuracy requirement. The main trend of development in localization is the cooperation between multi-stations and multi-algorithmic fusion. Based on the widely used LS optimization technology, we use RSSI as the data weight to fuse and revise several initial estimate values. As shown in the simulation we are able to obtain better accuracy and a more stable localization estimate value with the trilaminar data fusion technology.

2. The Overview LS Algorithm

LS is an old and effective estimation method [12-15]. It is able to estimate the signal parameters easily without any prior knowledge and only the observational signal model. At the same time it has the least square errors. Therefore, it is a widely used estimation method. The traditional measuring method can be divided into two types: Two-way Ranging (TWR) and One-way Ranging (OWR). Its mathematical formula is shown in Fig. 1. Where d_{AB} is the distance of BS and MS, c is the transmission speed of electromagnetic wave whose value is $3.0\times10^8 m/s$. There is much difficulty in achieving an accurate synchronization in the current cellular networks. Therefore, it is common to adopt Two-way Ranging to measure the distance between the MS and BS. In general, the LS estimation can be described as:

$$d_i = \sqrt{(x-x_i)^2 + (y-y_i)^2}\ , \tag{1}$$

where i=1,2,...,K. K means the number of BS nodes. Square both sides of Formula (1), we are able to get

$$d_i^2 = R - 2xx_i - 2yy_i + (x_i^2 + y_i^2) \Rightarrow xx_i - yy_i - 0.5R^2 = \frac{1}{2}(x_i^2 + y_i^2 - d_i^2)\ , \tag{2}$$

where $R = \sqrt{x^2 + y^2}$, then Formula (2) can be presented in the following matrix form,

$$H\theta = X\ , \tag{3}$$

where

$$H = \begin{bmatrix} x_1 & y_2 & -0.5 \\ \vdots & \vdots & \vdots \\ x_k & y_k & -0.5 \end{bmatrix},\ \theta = \begin{bmatrix} x \\ y \\ R^2 \end{bmatrix},$$

$$X = \frac{1}{2}\begin{bmatrix} x_1^2 + y_1^2 - d_1^2 \\ \vdots \\ x_k^2 + y_k^2 - d_k^2 \end{bmatrix}$$

We can make the error reach to the minimum only when we can get $J(\theta)$ to become the minimum. Thus

$$\frac{\partial J(\theta)}{\partial\theta} = \frac{\partial[(X-H\theta)^T(X-H\theta)]}{\partial\theta} = -2H^T(X-H\theta) = 0 \\ \Rightarrow \theta = (H^TH)^{-1}H^TX \tag{4}$$

The θ we have got from this calculation is the estimate coordinate point of LS of MS. However, as the localization accuracy is not high enough and its function cannot be evaluated in the LS localization algorithm, therefore, its accuracy needs to be improved further.

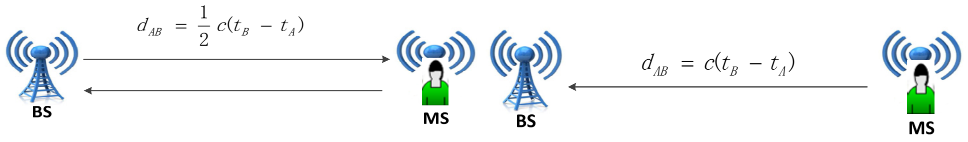


Fig. 1. TWR and OWR.

3. RSSI

The relationship between the launching rate and receiving rate of the wireless signal can be presented by Formula (5) [16-18],

$$P_{Bs} = P_{Ms} / r^n\ , \tag{5}$$

where P_{Bs}, P_{Ms}, r, n indicates the receiving rate, launching rate, distance and transmitted divisor respectively. Among them, the magnitude of the transmitted divisor depends on the environment of the signal transmission. Once we obtain the logarithm of Formula (5), then we can get

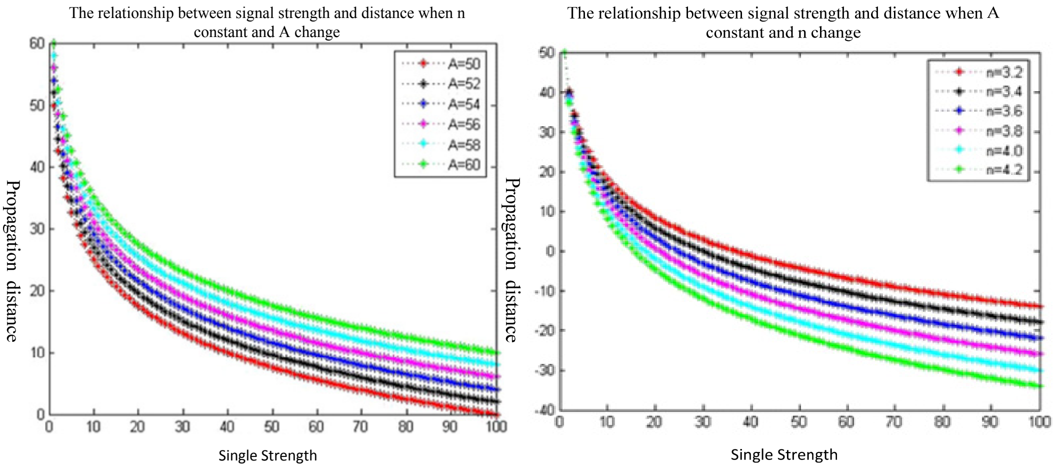
$$10n\lg r = 10\lg P_{Ms}/P_{Bs} \Rightarrow 10\lg P_{Bs} = A - 10n\lg r \tag{6}$$

Among them, A is the receiving rate of the signal when the signal is transmitted in free space for 1m. $10n\lg r$ is the manifestation of the receiving rate of signal converted into dBm, and it can be recorded as

$$P_{Bs}(dBm) = A - 10n\lg r \tag{7}$$

From formula (6), we are able to derive the relation between the strength of the receiving rate and transmitting distance depending on the two divisors A and n. The influences are shown in flowing.

From Fig. 2, we can see that the declination of the signal during the transmitting will become smaller, and the signal can be sent to farther when n (the transmitting divisor) receives the minimum. Furthermore, the transmitting divisor depends mainly on the interferences of the wireless signal in the air, such as declination, reflection and the multi-path effect. The smaller the interference is, the smaller the transmitting divisor will be, and the farther the transmitting distance. Thus, the transmitting curve of the wireless signal would be closer to the theoretical curve, and the distance measured based on the RSSI would be more accurate. Upon deeper analyses, we understand that there would be more errors and less accuracy in the signal S when the distance is increased. Therefore, we can change the strength of the signal of reception into an authentic R.


The relationship between signal strength and distance when n constant and A change

The relationship between signal strength and distance when A constant and n change

Fig. 2. The relationship between signal strength and distance.

4. The Three-Layer Data Fusion Algorithm

4.1. Achieving the First Layer

As shown in Fig. 3, we are able to obtain five groups of distances (d_1, d_2, d_3, d_4, d_5) as there are five BS and an MS [19]. We can then form a 5×4 matrix arbitrarily when we choose four out of five as a group randomly in these groups, as shown in Formula (8).

$$\begin{bmatrix} d_1 \\ d_2 \\ d_3 \\ d_4 \\ d_5 \end{bmatrix} \Rightarrow\Rightarrow \left\{ \begin{bmatrix} d_1 & d_2 & d_3 & d_4 \\ d_1 & d_2 & d_3 & d_5 \\ d_1 & d_2 & d_4 & d_5 \\ d_2 & d_3 & d_4 & d_5 \\ d_1 & d_3 & d_4 & d_5 \end{bmatrix} \right. \tag{8}$$

We estimated the distance of each group LS M times and adopt the average value of the M times' estimates. We can then obtain the more accurate estimate nodes (x_1, y_1),(x_2, y_2), (x_3, y_3), (x_4, y_4), (x_5, y_5), that is

$$\begin{bmatrix} d_1 & d_2 & d_3 & d_4 \\ d_1 & d_2 & d_3 & d_5 \\ d_1 & d_2 & d_4 & d_5 \\ d_2 & d_3 & d_4 & d_5 \\ d_1 & d_3 & d_4 & d_5 \end{bmatrix} \xrightarrow{(H^T H)^{-1} H^T X} \Rightarrow\Rightarrow\Rightarrow\Rightarrow \begin{bmatrix} (x_1, y_1) \\ (x_2, y_2) \\ (x_3, y_3) \\ (x_4, y_4) \\ (x_5, y_5) \end{bmatrix} \tag{9}$$

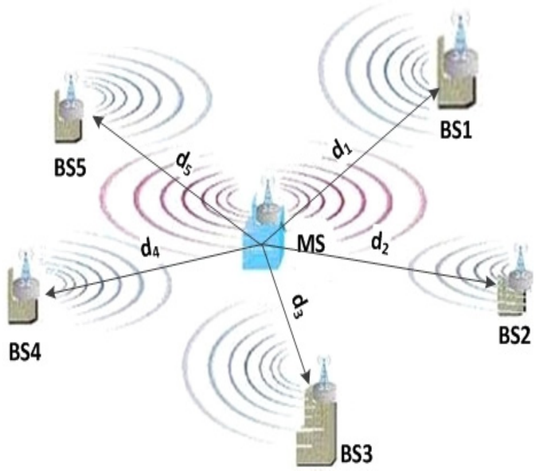


Fig. 3. Localization nodes topology.

4.2. Achieving the Second Layer

First, we work out the average value of the five nodes obtained from the first layer, and we then use the five estimates and their average values to derive its square error. The largest magnitude is apparently the abnormal data. We delete the abnormal data and delete the relevant weight of RSSI at the same time. And finally, we obtain the four estimating nodes.

$$(\bar{x}, \bar{y}) = (\frac{x_1 + x_2 + x_3 + x_4 + x_5}{5}, \frac{y_1 + y_2 + y_3 + y_4 + y_5}{5}) \tag{10}$$

$$(x, y)_{yc} = \max(\sqrt{(x_i - \bar{x})^2 + (y_i + \bar{y})^2} \quad i = 1,2,...,5. \tag{11}$$

$$\begin{bmatrix} (x_1, y_1) \\ (x_2, y_2) \\ (x_3, y_3) \\ (x_4, y_4) \\ (x_5, y_5) \end{bmatrix} \overset{delect \ \max(\bar{x}, \bar{y})}{\Rightarrow\Rightarrow\Rightarrow\Rightarrow} \begin{bmatrix} (x_1, y_1) \\ (x_2, y_2) \\ (x_3, y_3) \\ (x_4, y_4) \end{bmatrix} \tag{12}$$

4.3. Achieving the Third Layer

We can make the square error reach to the minimum by using the localization through LS to estimate, however there are still some errors caused by residual. This kind of error cannot be avoided, in this paper, we can use the weight addition method to reduce it. Here, we turn the signal obtained from BS into the least accurate value and we add weight to LS (r). Finally, the most optimized estimate nodes of export (X,Y).

$$(X, Y) = \left(\frac{x_1 r_1 + x_2 r_2 + x_3 r_3 + x_4 r_4}{4}, \frac{y_1 r_1 + y_2 r_2 + y_3 r_3 + y_4 r_4}{4}\right) \tag{13}$$

The above trilaminar data fusion model can be presented as in Fig. 4.

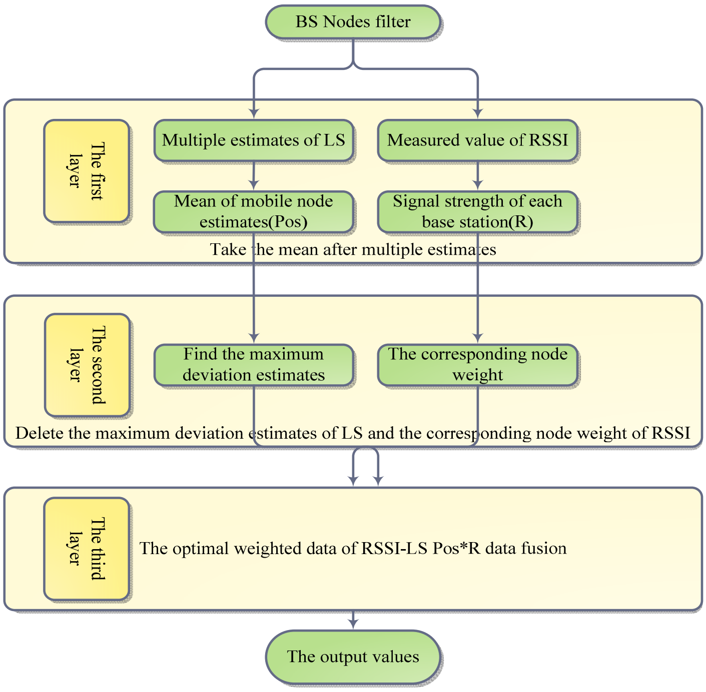


Fig. 4. The trilaminar data fusion model.

5. Data Simulation

We use the MATLAB simulator to perform the simulating experiment on the efficiency of the algorithm in this study. In addition, we have analyzed and compared the LS localizational algorithm. In the simulation, the launching rate of MS is 52 dBm. The transmitting environment is a log-normal distribution model. We aim mainly at the localization of static moving nodes using the $MS(1000,2000)$ as estimating nodes (MS), $BS1(0,0)$, $BS2(3000\sqrt{3},3000)$, $BS3(0,6000)$, $BS4(-3000\sqrt{3},3000)$ and $BS5(3000\sqrt{3},3000)$ as the five base nodes. In general, we regard the error's square of the localization result as the localization accuracy (AVG) [20].

$$AVG = \sqrt{(X-x)^2 + (Y-y)^2} \tag{14}$$

The estimating experiment managed to obtain the optimized moving nodes' estimation value of the LS-RSSI three-layer data fusion algorithm. The numbers in Table1 are the estimates of LS before being fused as well as certain localization orientation values of moving nodes in the LS-RSSI algorithm after undergoing a three-layer data fusion. Fig. 4 is the most accurate LS when compared with LS-RSSI.

From Table 1, we can see that, compared with the single LS localization algorithm, the estimated value of moving nodes of the LS-RSSI three-layer fusion localization algorithm is closer to the real moving nodes. From Fig. 5, we can see that, compared with the single LS algorithm, the accuracy of LS-RSSI trilaminar fusion localization algorithm has improved greatly. The simulation shows that weight addition for the LS algorithm with RSSI is an effective and feasible method.

Table 1. The moving nodes' two-dimension value of LS and LS-RSSI.

LS -values	X	1016.5	1006.2	1004.6	1012.7	1011.2
	Y	1990.7	2016.3	2015.6	2018.2	2009.2
LS-RSSI values	X	1001.5	1004.2	1003.9	1005.9	1002.9
	Y	2000.5	1999.0	2006.4	2005.6	1999.3

6. Conclusion

In this paper, we have developed a LS-RSSI trilaminar data fusion localization algorithm based on RSSI weight addition based on the study of the LS and RSSI localization algorithms. Through several methods such as the optimal selection of base stations, the location of each basic station in turn and the deletion of abnormal data, we have resolved the problem of the lack of localization accuracy in the LS localization algorithm effectively. Through the RSSI weight addition data fusion algorithm, we have obtained a more optimized localization estimate value and improved its accuracy markedly. The result in the simulation shows that the LS-RSSI localization algorithm does not need additional hardware, and at the same time, the calculation is small. It can also improve localization accuracy more stably and effectively than ordinary LS localization algorithm. The LS-RSSI is thus an effective and feasible method.

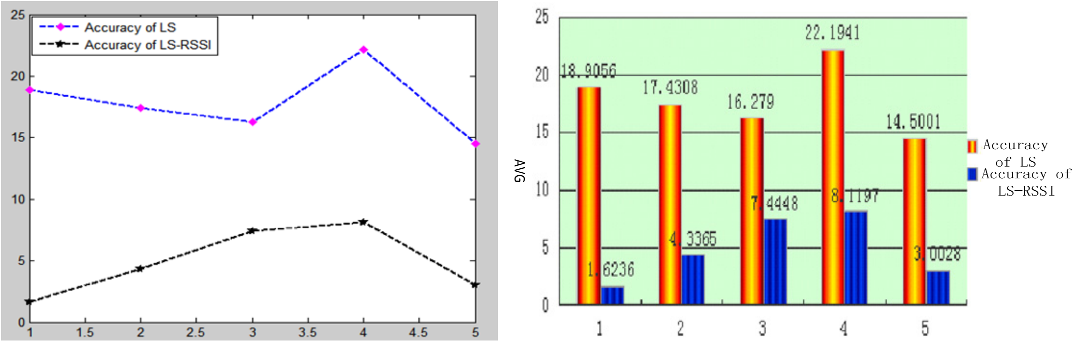


Fig. 5. Accuracy comparison between LS and RSSI-LS.

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