A Survey of Localization in Wireless Sensor Network

Hao Zhang[1, a], Xiaojun Mei[2, b]

[1] Merchant Marine College, Shanghai Maritime University, Shanghai, 201306, China;

[a]haozhangsmu@163.com, [b] xjmei94@163.com @163.com

Abstract

With the increasing demand for localization in large-scale and harsh environments, low-cost, highly scalable wireless sensor network(WSN) localization is one of the key techniques in wireless sensor networks. The location of nodes in wireless sensor networks is to use the information between nodes to determine the position of the node through a specific algorithm, such as connectivity information and distance information. This paper introduces the concept and application of wireless sensor network and localization technology is briefly introduced and four common measurement models in wireless sensor network localization are introduced: AOA, TOA, TDOA, and RSSI. Moreover,we divide the location estimation methods in WSN into rang-based and rang-free. In the range-based localization technology, we introduce some common range-based localization technologies; In the range-free localization technology, some common rang-free localization technologies are systematically summarized and analyzed. Finally, these localization technologies are compared, and the future development of location estimation methods in WSN has prospected.

Keywords

Wireless Sensor Network, measurement models, rang-free localization, range-based localization.

1. Introduction

The emergence of the Wireless Sensor Network (WSN) is known as the core technology that has extraordinary significance for the future development of mankind. WSN is composed of many low-cost sensor nodes, which can realize data collection, environmental monitoring, node positioning, and other functions. The positioning of nodes is one of the research priorities. [1] Node positioning in WSN can play a big role in military surveillance, transportation, personnel assistance, environmental management, etc., such as placing some sensor nodes in a community or factory, when a fire occurs, fire The sensor node near the source sends the location coordinate information to the network, so that the rescuer can find the fire location in time, which will greatly help the fire extinguishing and the evacuation path planning of the personnel; in military monitoring, the wireless sensor network Positioning technology can be used to determine the position of the enemy and monitor the movement of the enemy, thus taking a strategic position. [2]

In the WSN localization technology, the anchor node refers to a node pre-configured in the WSN, and can determine its own position coordinates; the unknown node is a node randomly distributed in the area to be monitored by means of aircraft throwing or manual arrangement, and has a transmitting and receiving signal. Ability. According to different classification criteria, the node location technology can be divided into different algorithm groups. For example, according to whether the anchor node is needed in the network, it can be divided into anchor node location and anchor node-free positioning. According to the calculation method, it can be divided into centralized positioning and distributed positioning. According to the measurement information, it can be divided into ranging positioning and non-ranging positioning. [3] In classifying the positioning according to the measurement information, the ranging positioning needs to measure the distance or angle between the nodes, and the measurement model mainly includes AOA (Arrival Of Angle) [4], TOA (Time Of Arrival). [5], TDOA (Time Difference Of Arrival) [6], RSSI (Received Signal Strength Indicator) [7];

Ranging and positioning technology mainly includes trilateral positioning technology, triangulation technology, multilateral positioning technology, Chan [8] algorithm, MDS [9], DV - Distance [10]. Non-ranging positioning uses the connectivity of the network or the number of communication hops to locate the nodes. There are mainly centroid positioning algorithms [11], convex position algorithms [12], DV-hop [9, 13], APIT [14].

2. Measurement Models

2.1 AOA

The theory of AOA is to measure the angle between the unknown node and the anchor node in the communication range through the array antenna. [4] However, since the AOA requires the node to have an array antenna, the cost is high, which is not common in practical applications, and the signal When it is transmitted in the air, it is easily interfered by electromagnetic waves, non-line of sight (NLOS), etc., and has a certain influence on the accuracy of measurement. In view of the influence of non-line-of-sight on AOA, the literature [15] corrects the NLOS error by RBF neural network and then uses the least-squares method to obtain the estimated coordinates $Q=(x_i,y_i)$, and the mean value the first M data of Q is used as the starting point trace $X=Q\Lambda^{\frac{1}{2}}$, and the distance gate G is set to determine whether $G<\sqrt{(a_i-x_{i+1})^2+(b_i-y_{i+1})^2}$ holds true to update the tracked coordinates, but the neural network algorithm has a long training period and requires a large number of samples. The literature [21] performs wavelet decomposition on the measured signal $f(t)=\sum_{j=1}^{N}\sum_{k\in z}d_{j,k}\varphi_{j,k}(t)+\sum_{k\in z}c_{j,k}\delta_{j,k}(t)$, the wavelet coefficient valve is set to remove the noise, and finally the LS is used for coordinate calculation, which avoids the shortcomings of the training period based on the neural network algorithm in the literature [20], and the measurement result is better. .

2.2 TOA

The principle of TOA is to measure the distance by recording the signal propagation time between nodes. [3] Assume that anchor node A sends a signal at time t, the propagation speed of the signal is c, and the time when the signal reaches unknown node B is t_1, then the anchor The distance between node A and unknown node B is $d=c(t_1-t)$. Since the node that transmits the signal and the node that receives the signal record time, the TOA measurement model requires high clock synchronization for the node. TOA is also affected by non-line-of-sight (NLOS) interference and non-strict synchronization of the signal during signal transmission. For this paper [16], the Newton iteration method is used to iteratively calculate the estimated coordinates to reduce the influence of time measurement deviation. The measurement accuracy is improved without increasing the cost. In [17], the initially estimated coordinates are iteratively calculated using the Taylor expansion formula to obtain the quadratic coordinates, and the difference between the quadratic coordinates and the distance between the anchor node and the TOA measurement distance is corrected as the NLOS deviation, and then iteratively processed by Taylor series. Finally, the weighted least squares method is used for estimation, and the suppression effect on NLOS is better.

2.3 TDOA

TDOA is an improved TOA measurement model. The anchor node in the TOA transmits a signal to the anchor node and simultaneously transmits two signals (the propagation rates of the two signals are different). The distance between the nodes is calculated by the time difference of the signals, [6] reduces the need for clock synchronization. It is assumed that the propagation rates of the signals are v_1 and v_2, respectively. The time at which the unknown node receives the two signals is t_1 and t_2, respectively, and the distance between the anchor node and the unknown node is $d=(v_1-v_2)(t_2-t_1)$. For the influence of noise on the signal during propagation, the literature [18] performs filtering analysis and amplitude processing on the collected signal based on TDOA ranging, which reduces the influence of noise on signal interference.

2.4 RSSI

The RSSI-based localization technology calculates the distance between the unknown node and the anchor node by the strength of the signal sent by the unknown node. [10] Since the node modules of most wireless communication networks have the ability to obtain RSSI values, the sensor nodes do not need to add additional hardware devices, which greatly reduces the cost of the sensor network, so the RSSI is located in the sensor network. Applications are very common. There are currently three main types of wireless signal propagation models: the Free-Space model, the Two-Ray Ground Reflection model, and the Shadowing model. The Shadowing model is generally used to match the actual environment. The Shadowing model is expressed by:

$$P_r(d) = P_r(d_0) - 10n\lg\left(\frac{d}{d_0}\right) + X_\sigma \tag{1}$$

Where $P_r(d)$ is the received signal power of the unknown node from the anchor node d, and $P_r(d_0)$ is the received signal power of the unknown node from the anchor node d_0 , where d_0 is The reference distance is generally 1 to 2 m, where n is the path loss factor, the general value is between 2 and 4 and X_σ is a zero-mean Gaussian random variable.

In actual RSSI measurements, the measured RSSI values are generally inaccurate due to environmental factors. Literature [19] proposed a weighted probability localization algorithm, which divides the intersection region of anchor nodes received by unknown nodes into several grids, and assigns each RSSI valued differently according to the distance between the anchor nodes and the unknown nodes. The weight of each grid, through the confidence of each grid, to find the nearest grid to the unknown node, its centroid as the coordinates of the unknown node, compared to the traditional RSSI model, the accuracy has been greatly improved. Reference [20] used least squares to obtain a set of measured path attenuation index $N=(n_1,n_2,\cdots,n_x)$, and the mean is $M=\frac{n_1+n_2+\cdots+n_x}{x}$. According to the difference from the mean, each n is given a weight. The smaller the difference is, the larger the weight is, the more accurate the path attenuation index can be obtained, and the distance measurement effect is better.

3. Range-based localization

The range-based localization technology uses the distance information between the nodes obtained by the measurement model to calculate the coordinates of the unknown nodes. Several common ranging-based positioning techniques are introduced below.

3.1 Trilateration localization algorithm

As shown in Figure 1, suppose that there are three anchor nodes A, B, and C in the communication range of an unknown node D, and the coordinates are $(x_a,y_a),(x_b,y_b)$ and (x_c,y_c), and their distances to the unknown node $D(x_d,y_d)$ are d_a , d_b and d_c , respectively, and the relationship between the coordinates and distance between them can be obtained (2):

$$\begin{cases}(x_d-x_a)^2+(y_d-y_a)^2=d_a^2\\(x_d-x_b)^2+(y_d-y_b)^2=d_b^2\\(x_d-x_c)^2+(y_d-y_c)^2=d_c^2\end{cases} \tag{2}$$

Available from (2):

$$\begin{cases}2(x_a-x_c)x_d+2(y_a-y_c)y_d+x_c^2-x_a^2+y_c^2-y_a^2=d_c^2-d_a^2\\2(x_b-x_c)x_d+2(y_b-y_c)y_d+x_c^2-x_b^2+y_c^2-y_b^2=d_c^2-d_b^2\end{cases} \tag{3}$$

Let $A=\begin{bmatrix}2x_a-2x_c & 2y_a-2y_c\\2x_b-2x_c & 2y_b-2y_c\end{bmatrix} X=\begin{bmatrix}x_d\\y_d\end{bmatrix} b=\begin{bmatrix}d_e^2-d_a^2+x_a^2-x_c^2+y_a^2-y_c^2\\d_e^2-d_b^2+x_a^2-x_b^2+y_a^2-y_b^2\end{bmatrix}$

So Equation (3) can be written in the form of a linear equation AX = b. We can obtain $X = A^{-1}b$ and the coordinates of $D(x_d, y_d)$.

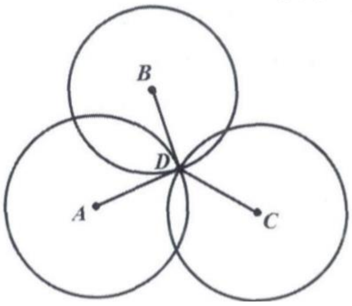

Figure 1：Trilateration localization algorithm

The trilateration algorithm is ideally well positioned. However, when the distance measurement is not accurate because the equation (3) simplifies the three nonlinear constraint equations into two linear constraint equations, although the calculation is simplified, the positioning accuracy is degraded.

3.2 Triangulation localization algorithm

The triangulation localization algorithm uses the measurement of AOA, as shown in Figure 2. The communication range of the unknown node $D(x_d, y_d)$ has three anchor nodes $A(x_a, y_a)$, $B(x_b, y_b)$, $C(x_c, y_c)$, and the angles of D to A, B, and C are ∠ADC, ∠ADB, and ∠BDC, respectively. For the anchor nodes A and C, the arc AC can only get one circle if it is within the ABC. Assume the coordinates of the center of the circle is (x_o, y_o) with a radius of d_o.

$$\beta = \angle AOC = (2\pi - 2\angle ADC) \tag{4}$$

$$\begin{cases} d_o = \sqrt{(x_o - x_a)^2 + (y_o - y_a)^2} \\ d_o = \sqrt{(x_o - x_c)^2 + (y_o - y_c)^2} \\ 2d_o^2 - 2d_o^2 \cos\beta = \sqrt{(x_a - x_c)^2 + (y_a - y_c)^2} \end{cases} \tag{5}$$

From the formulas (4) and (5), the center coordinates (x_o, y_o) and radius d_o of the circle O can be obtained. Similarly, the center coordinates and radius of A, B, and ∠ADB and the center coordinates and radius of B, C, and ∠CBD can be obtained, and then the coordinates of unknown node D is calculated according to the trilateration localization algorithm.

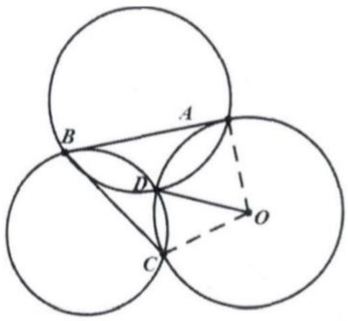

Figure 2：Triangulation localization algorithm

3.3 Multilateral positioning

If an unknown node $A(x, y)$ in the WSN can receive the signal from $n(3 \le n)$ anchor nodes, the coordinates of which are $(x_1, y_1), (x_2, y_2) \cdots (x_n, y_n)$. The distance between the unknown node and each anchor node are $d_1, d_2 \cdots d_n$, then the distance between A and n anchor nodes can be expressed by:

$$\begin{cases}(x-x_1)^2+(y-y_1)^2=d_1^2\\(x-x_2)^2+(y-y_2)^2=d_2^2\\\quad\vdots\\(x-x_n)^2+(y-y_n)^2=d_n^2\end{cases}\tag{6}$$

Equation (6) can be rewritten as:

$$\begin{cases}x_1^2-x_n^2+y_1^2-y_n^2-2(x_1-x_n)x-2(y_1-y_n)y=d_1^2-d_n^2\\x_2^2-x_n^2+y_2^2-y_n^2-2(x_2-x_n)x-2(y_2-y_n)y=d_2^2-d_n^2\\\quad\vdots\\x_{n-1}^2-x_n^2+y_{n-1}^2-y_n^2-2(x_{n-1}-x_n)x-2(y_{n-1}-y_n)y=d_{n-1}^2-d_n^2\end{cases}\tag{7}$$

Equation (7) be rewritten as the form of the equation $AX=b$, where

$$A=\begin{bmatrix}2x_1-2x_n & 2y_1-2y_n\\2x_2-2x_n & 2y_2-2y_n\\\vdots & \vdots\\2x_{n-1}-2x_n & 2y_{n-1}-2y_n\end{bmatrix} X=\begin{bmatrix}x\\y\end{bmatrix} \text{ and } B=\begin{bmatrix}d_n^2-d_1^2+x_1^2-x_n^2+y_1^2-y_n^2\\\vdots\\d_n^2-d_{n-1}^2+x_{n-1}^2-x_n^2+y_{n-1}^2-y_n^2\end{bmatrix}$$

The coordinate matrix $X=(A^TA)^{-1}A^TB$ can be obtained by solving the least-squares method.

3.4 Chan algorithm

The principle of the Chan algorithm is to calculate coordinates by TDOA measurements, and the positioning is better when the noise in the TDOA measurement is subject to Gaussian distribution. With an unknown node A with a coordinate of (x,y), and the coordinate of the anchor I is (x_i,x_i). The distance between A and I is $D_i=\sqrt{(x_i-x)^2-(x_i-y)^2}$, and squared on both sides is available at the same time can obtain:

$$D=(x_i-x)^2-(y_i-y)^2=K_i-2x_ix-2y_iy+x^2+y^2\tag{8}$$

Where $K_i=x_i^2+y_i^2$ and the distance difference between the unknown node to the 1^{th} anchor node and the i^{th} anchor node is:

$$D_{i,1}=D_i-D_1=\sqrt{(x_i-x)^2-(y_i-y)^2}-\sqrt{(x_1-x)^2-(y_1-y)^2}\tag{9}$$

$$D_{i,1}^2+2D_{i,1}D_1+D_1^2=K_i-2x_ix-2y_iy+x^2+y^2\tag{10}$$

Assume i=1:

$$D_1^2=K_i-2x_ix-2y_iy+x^2+y^2\tag{11}$$

Equation (10) minus formula (11) can obtain:

$$D_i^2+2D_{i,1}D_1=-2x_{i,1}x-2y_{i,1}y+K_i-K_1\tag{12}$$

Where $x_{i,1}=(x_i-x_1)$ and $y_{i,1}=(y_i-y_1)$.

The coordinates of the unknown node A can be obtained if the unknown node can receive 3 anchor node information sets:

$$\begin{bmatrix}x\\y\end{bmatrix}=-\begin{bmatrix}x_{2,1} & y_{2,1}\\x_{3,1} & y_{3,1}\end{bmatrix}^{-1}\times\left\{\begin{bmatrix}D_{2,1} & D_1+\frac{1}{2}\begin{bmatrix}D_{2,1}^2-K_2+K_1\\D_{3,1}^2-K_3+K_1\end{bmatrix}\end{bmatrix}\right\}\tag{13}$$

When an unknown node can receive information sets of 4 or more (n≥4) anchor nodes, its position with TDOA noise is estimated as:

$$Z_a\approx\left((G_a^TQ^{-1}G_a)^{-1}G_a^TQ^{-1}h\right)\tag{14}$$

Where $G_a = \begin{bmatrix} x_{2,1} & y_{2,1} & D_{2,1} \\ x_{3,1} & y_{3,1} & D_{3,1} \\ \vdots & \vdots & \vdots \\ x_{n,1} & y_{n,1} & D_{n,1} \end{bmatrix}$ $h = \frac{1}{2}\begin{bmatrix} D_{2,1}^2 & -x_3^2 & -y_3^2 & +x_1^2+y_1^2 \\ D_{3,1}^2 - x_3^2 - y_3^2 & +x_1^2 & +y_1^2 & \\ \vdots & & & \\ D_{n,1}^2 - x_n^2 & -y_n^2 & +x_1^2 & +y_1^2 \end{bmatrix}$ and Q is the covariance matrix of TDOA.

Assume $Z_a' = \begin{bmatrix} (x-x_1)^2 \\ (y-y_1)^2 \end{bmatrix}$, can get the formula (15)

$$Z_a' = \begin{bmatrix} (x-x_1)^2 \\ (y-y_1)^2 \end{bmatrix} \approx \left(G_a^{T} B^{-1} G_a Q^{-1} G_a B^{-1} G_a'\right)^{-1} \left(G_a^T B^{-1} G_a Q^{-1} G_a B^{-1}\right) h' \tag{15}$$

Where $G_a' = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 1 \end{bmatrix}$ $h' = \begin{bmatrix} (Z_{a,1} - x_1)^2 \\ (Z_{a,2} - y_1)^2 \\ Z_{a,1}^2 \end{bmatrix}$ $B' = \operatorname{diag}\{x^0 - x_1, y^0 - y_1, r_1^0\}$

We can get the final estimated coordinates as:

$$Z_p = -\sqrt{Z_a'} + \begin{bmatrix} x_1 \\ y_1 \end{bmatrix} \text{ or } Z_p = \sqrt{Z_a'} + \begin{bmatrix} x_1 \\ y_1 \end{bmatrix}$$

4. Range-free localization.

4.1 Centroid Algorithm

The Centroid Algorithm was proposed by Bulusu et al. of the University of Southern California. [11] The main steps are as follows:

The anchor node sends a set of information to the nodes in the communication range, and the information set includes the anchor node's own ID and coordinates.

The unknown node determines whether the received information set of the anchor node exceeds the set threshold M. If the unknown node A receives the information set broadcast by N ($N \le M$) anchor nodes within its communication range, record the $ID\{B_1, B_2, \cdots, B_n\}$ of these anchor nodes and the position coordinates $\{(x_1, y_1), (x_2, y_2), \cdots, (x_n, y_n)\}$.

The estimated coordinate A' of A is the centroid of the two-dimensional figure formed by the neighbor anchor node of A:

$$A'(x, y) = \left(\frac{x_1 + x_2 + \cdots + x_n}{n}, \frac{y_1 + y_2 + \cdots + y_n}{n}\right)$$

The centroid algorithm is a positioning algorithm that only needs to rely on the connectivity of the network, without the need to additionally increase the cost of the wireless sensor network. When the anchor nodes in the network are evenly distributed and have a high density, they have a good positioning effect. However, when the density of anchor nodes in the network is low and the anchor nodes in the network are unevenly distributed, the positioning error is very large. According to the data [21], the distance from the anchor node to the unknown node measured by the RSSI model is used. The weight of each anchor node is weighted by the reciprocal of the distance, and the positioning error is lower than the traditional centroid localization algorithm. The paper [19] combines each of the N anchor nodes of the unknown node into a triangle and sets the coordinates of the three anchor nodes A, B, and C as (x_1, y_1), (x_2, y_2), and (x_3, y_3), respectively. d_1, d_2 and d_3 are the distances from anchor nodes A, B, and C to unknown nodes, respectively. Then the weights of anchor nodes A, B, and C are $\frac{1}{d_1 + d_2}$, $\frac{1}{d_3 + d_2}$ and $\frac{1}{d_3 + d_1}$, respectively. Positioning accuracy is improved.

The literature [22] changed the weight of the literature [19] $\frac{1}{d_1^n}+\frac{1}{d_2^n},\frac{1}{d_2^n}+\frac{1}{d_3^n},\frac{1}{d_1^n}+\frac{1}{d_3^n}$, where n is the correction factor. Compared with the literature [114], the anchor nodes closer to the unknown nodes have larger weight values and higher positioning accuracy.

4.2 DV - hop

The DV-hop algorithm is an algorithm proposed by NiCuleScu et al. to use node hopping for node location. [9, 13] The main steps are as follows:

All nodes in the network send information to nodes within the communication range, including $\{i_{id}, x_i, y_i, hop_{ij}\}$. Where i_{id} is the label of the signal transmitted by node i, (x_i, y_i) is the coordinate of i_{id} (passed if the coordinates are known, otherwise it is empty), hop_{ij} is the number of hops between nodes i and j, and the initial hop count hop_{ij} is set to 0. hop_{ij} increments by 1 after node I receiving the information passed by another node j. Traversing the entire network, if the node receives multiple hop_{ij} values of the same i_{id}, it compares with the same iid in its own data table, and records the smallest hop_{ij} it receives, so that each node stores it except itself. Minimum hop count information of other nodes

The distance between each anchor node is calculated by the known coordinate information of the anchor node. The minimum hop count between each anchor node can be obtained by step 1, and the average distance per hop can be calculated by the formula (16).

$$D_{size} = \frac{\sum_{i \neq j} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum_{i \neq j} hop_{ij}} \tag{16}$$

Calculate the estimated distance between the unknown node and the anchor node $D = hop_{ij(\min)} * D_{size}$, and then calculate the coordinates by the rang-based localization technique.

As shown in Figure 3, it is a micro-WSN consisting of 10 nodes. x, y, and z are three anchor nodes, and o is an unknown node. The distance between x and y is dxy', the distance between y and z is dyz', the minimum hop count from x to o is 3, the minimum hop count from y to o is 3, and the minimum hop count from z to o is 2. The average distance per hop for this network is $\frac{(dxy'+dyz)}{2}$,then calculate the distance from x to o is $\frac{3*(dxy'+dyz)}{2}$, the distance from y to o is $\frac{3*(dxy'+dyz)}{2}$, and the distance from z to o is $\frac{2*(dxy'+dyz)}{2}$. Finally,we can obtain the coordinates of o.

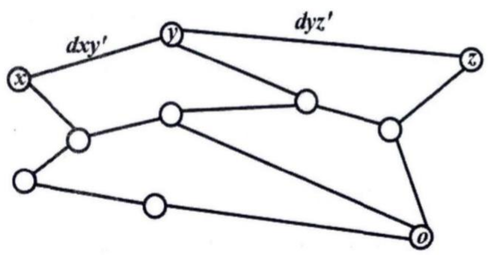

Figure 3: Dv-hop

4.3 Approximation point-in-triangulation test(APIT)

APIT is also called the approximate triangle inner point test method. [14] The main idea is that the anchor node broadcasts a set of information to the neighbor unknown node. The set includes the ID of the anchor node, the distance between nodes, and connectivity. The positioning error is reduced by removing some anchor nodes that are less correlated with unknown nodes, thereby achieving a reduction in positioning error.

Assuming that the unknown node receives signals from n anchor nodes, the n anchor nodes can form C_N^3 triangle regions. It is judged whether or not the unknown node is within these triangles, and if so, the anchor node IDs constituting the triangular area are recorded so that the centroid of the intersection of these triangles is used as the estimated coordinates of the unknown node. Ideally, to determine if a point is inside a triangle, we can move the point in either direction. If the point is away from the three vertices of the triangle, then the point is outside the triangle, otherwise, the point is inside the triangle. However, this method is not suitable due to the slow movement of the node and the non-movability of the special node. Therefore, in the wireless sensor network, it can be judged whether the neighbor node of the unknown node is away from or close to the three anchor nodes at the same time. Inside the triangle. In [23], for the nodes in the network that do not meet the APIT positioning conditions (such as the anchor nodes communicating with unknown nodes are on the side of the unknown node), an improved algorithm IAPT is proposed to use the nodes that do not meet the APIT positioning conditions. Three-sided measurement method and other methods are used for processing, and the scalability is good. Reference [24] proposed to reduce the positioning error by setting the movable anchor node and multiple positioning to reduce the positioning error and improve the positioning accuracy.

5. Conclusion

Due to the distance information obtained by the rang-based localization technology through these models is relatively accurate, the positioning accuracy is higher than that of the range-free localization technology, but its higher hardware cost leads to the lower application level, generally in some small WSNs requiring high precision positioning. Application. The range-free localization technology is greatly affected by the distribution and number of anchor nodes. It only uses the connectivity of the network to locate. The location estimation error of unknown nodes is large, and the positioning accuracy is low. However, due to its low network deployment cost, It is widely used in many large WSNs.

This paper summarizes and introduces the measurement models in WSN and some common localization techniques, and compares these localization techniques. At present, the localization problem in wireless sensor networks is not limited to the positioning of two-dimensional space and the positioning of fixed nodes. The positioning of mobile nodes [26-27] and the positioning of three-dimensional space [25] are also hot topics. Although some of the current localization technologies are also very mature, there are still many problems to be solved in node positioning, such as insufficient node energy, ranging accuracy, and network optimization. With the increasing requirements for positioning accuracy and positioning range, the research of WSN positioning technology tends to the fusion of localization algorithms, the cooperative localization between nodes [28], the combination of localization technology and machine learning [29-25], etc. direction

Acknowledgements

This work was supported by the National Natural Science Foundation of China (51279099, 51579143) and the Shanghai Committee of Science and Technology, China (Grant No. 18040501700).

References

[1] Kulaib A R,Shubair R M,Al − Qutayri M A,et al. An overview of localization techniques for Wireless Sensor Networks [C] / /International Conference on Innovations in Information Technology. IEEE,2011:167 −172.

[2] C. Wang and L. Xiao, “Sensor localization in concave steplessents,” ACM Transactions on Sensor Networks, vol. 4, no. 1, article 3, 2008.

[3] R.NiuandP.Varshney, “Target location estimation in wireless sensor networks using binary data,” in Proceedings of the 38th International Conference on Information Sciences and Systems, pp. 17–19, Princeton, NJ, USA, March 2004.
[4] J. Liu, E.L. Chen and Z.T. He: Journal of Shi Jia Zhuang Railway Institute (Natural Science), Vol. 22 (2009) No. 4, p.40-42.
[5] Q. D. Zeng, Q. E. Li: Progress in Civil Engineering, Vol. 32 (2012) No. 9, p. 3077-3080.
[6] HongyuShi,Cao J. A new hybrid algorithm on TDOA localization in wireless sensor network［C］/ / IEEE International Conference on Information and Automation. IEEE,2011: 606 －610.
[7] Girod L,Bychkovskiy V,Elson J,et al. Locating tiny sensors in time and space: a case study ［C］/ / IEEE International Conference on Computer Design: Vlsi in Computers and Processors,2002. Proceedings. IEEE,2002:214 －219.
[8] Chan Y T,Ho K C. A simple and efficient estimator for hyperbolic location ［ J］. Signal Processing IEEE Transactions on,1994, 42(8): 1905 －1915.
[9] Shang Y, Ｒuml W,Zhang Y,et al. Localization from mere connectivity［C］/ / ACM International Symposium on Mobile Ad Hoc NETWOＲKING ＆ Computing. ACM,2003: 201 －212.
[10] Niculescu D,Nath B. DV Based Positioning in Ad Hoc Networks ［ J］. Telecommunication Systems,2003,22(1): 267 －280.
[11] Bulusu N,Heidemann J,Estrin D. GPS － less low cost outdoor optimization for very small devices ［ J］. IEEE Personal Communications,2000, 7(5) :28 －34.
[12] Doherty L,Pister K S J,El Ghaoui L. Convex position estimation in wireless sensor networks［C］/ / INFOCOM2001 . Twentieth Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE. IEEE, 2001:1655 －1663.
[13] Niculescu D, Nath B. Ad hoc positioning system ［ J］ . Globecom, 2003,(3) :1734 －1743.
[14] He T, Huang C, Blum B M, et al. Ｒange － free localization schemes for large scale sensor networks ［C］/ / International Conference on Mobile Computing and Networking,MOBICOM 2003, 2003, San Diego, Ca, Usa, September. DBLP, 2003:81 －95.
[15] M. P. Wylie and J. Holtzman, “The non-line of sight problem in mobile location estimation,” in Proceedings of the 5th IEEE International Conference on Universal Personal Communications Record (ICUPC ’96), pp. 827–831, Cambridge, Mass, USA, October 1996.
[16] H. P. Tan, R. Diamant, and W. K. G. Seah, “A survey of techniques and challenges in underwater localization,” Ocean Engineering, vol. 38, no. 14-15, pp. 1663–1676, 2011.
[17] H.LimandJ.C.Hou,“Distributedlocalizationforanisotropic sensor networks,” ACM Transactions on Sensor Networks, vol. 5, no. 2, article 11, 2009.
[18] X. Qu and L. Xie, “Source localization by TDOA with random sensor position errors—part I: static sensors,” in Proceedings of the 15th International Conference on Information Fusion, pp. 48–53, Singapore, July 2012.
[19] X. Luo, W. J. O’Brien, and C. L. Julien, “Comparative evaluation of Received Signal-Strength Index (RSSI) based indoor localization techniques for construction jobsites,” Advanced Engineering Informatics, vol. 25, no. 2, pp. 355–363, 2011.
[20] K. Yu and Y. J. Guo, “Statistical NLOS identification based on AOA, TOA, and signal strength,” IEEE Transactions on Vehicular Technology, vol. 58, no. 1, pp. 274–286, 2009.
[21] X. Shen, S. Yang, J. He, Z. Huang, Improved localization algorithm based on RSSI in low power Bluetooth network, 2nd International Conference on Cloud Computing and Internet of Things (CCIOT), 2016, pp. 134–137.
[22] L. Oliveira, HB. Li, L. Almeida, TE. Abrudan, RSSI-based relative localisation for mobile robots, Ad Hoc Netw. 13 (February(Part b)) (2013) 321–335.
[23] Y. Gu, A. Lo, I. Niemegeers, A survey of indoor positioning systems for wireless personal networks, IEEE Commun. Surv. Tutorials 11 (March(1)) (2009) 13–32.

[24] B. Han, L. Zhao, An indoor positioning algorithm based on Wi-Fi fingerprint and inertial navigation system, 36th Chinese Control Conference, July, 2017, pp. 26–28.
[25] Tang T, Liu H, Song H, et al. Support Vector Machine Based Range - Free Localization Algorithm in Wireless Sensor Network [C] / /International Conference on Machine Learning and Intelligent Communications. Springer, Cham, 2016:150 -158.
[26] Hu L, Evans D. Localization for mobile sensor networks [C] / /Proceedings of the 10th annual international conference on Mobile computing and networking. ACM, 2004:45 -57.
[27] Baggio A, Langendoen K. Monte Carlo localization for mobile wireless sensor networks [J] . Ad Hoc Networks, 2008, 6(5) :718 -733.
[28] Zhang P, Lu J,Wang Q. Performance bounds for relative configuration and global transformation in cooperative localization [J] . ICT Express, 2016, 2(1) :14 -18.
[29] Nguyen X L. LOCALIZATION PROBLEM IN SENSOR NETWORKS: THE MACHINE LEARNING APPROACH [C] / /2012.