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STUDY ON UNMANNED SHIP POSITIONING ALGORITHM BASED ON MAXIMUM LIKELIHOOD METHOD AND MIN-MAX LOCALIZATION ALGORITHM

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ABSTRACT

The common using positioning algorithm include GPS, Beidou navigation and other positioning technologies in application field of unmanned ship at present. However, the civil GPS, Beidou navigation and other technologies have low precision and high price. In order to meet the research requirement, an unmanned ship positioning algorithm based on maximum likelihood estimation and Min-Max localization algorithm is proposed in this paper. This paper designs accuracy and stability experiment to verify the performance of the algorithm. By analysing the experimental data, this paper concludes that the positioning algorithm has well accuracy and stability with lower costs. So that it can be applied to the requirements of positioning in short range.

Keywords: maximum likelihood estimation, Min-Max localization algorithm, unmanned ship.

1. INTRODUCCTION

With the development of technological progress of unman-ed ship, unmanned ships are widely used in marine environmental monitoring, underwater topographic survey, water quality testing and other fields because of its unique characteristic such as high security, high efficiency and so on[1]

Project team of this paper proposes that unmanned ship can be used to detect the sediment scour of underwater abutment and generate 3D mapping results based on the above characteristics of unmanned ships. Most of positioning technologies used by unmanned ships in the above application fields are GPS, Beidou navigation and other satellite positioning technology[2][3]. However, for the errors in satellite orbit and satellite clock, the influence of troposphere and ionosphere on signals, the SA(Selective Availability) protection policy with the greatest impact and other reasons, the positioning accuracy of civil GPS is only about 100 meters. It may be ignored in some fields that require remote-control such as Marine environmental monitoring, underwater topographic survey on a larger scale, but it is unacceptable in the field of detecting the sediment scour of underwater abutment. Although the positioning error of GPS-RTK positioning technology developed in recent years[4] can achieve centimeter-level, the cost of it is too high. For these reasons, this paper proposes an unmanned ship positioning algorithm based on maximum likelihood estimation and Min-Max localization algorithm.

The Min-Max localization algorithm based on ranging[5] is a kind of node location algorithms in the field of sensor network. The familiar node location algorithms based on ranging in the field of sensor network are usually divided into three phases: ranging phase, positioning phase, iterative refinement phase. At the ranging phase, the frequently-used ranging algorithm include the algorithm based on TOA(time of advent), TDOA(time difference of arrival), AOA(activity on arcs), RSSI(received signal strength indicator) and so on[6]. However, this paper measures distance by the base station because of the difference between the fields of unmanned ship positioning and sensor network. At the positioning phase, usually, the distance between the reference node and the blind node is measured by the above ranging technology to calculate the location of the blind node. In the positioning stage of this paper, the measured distance is used to calculate the position of the label. And the iterative refinement phase has no significant influence on the unmanned ship positioning algorithms, so it is not considered.

2. PRINCIPLE AND ALGORITHM

2.1 Maximum likelihood estimation

Maximum likelihood estimation is an improved algorithm for trilateral measurement and positioning algorithm. The main idea of maximum likelihood estimation in this paper is to form a set of equations based on three or more distance between base stations and tags, and uses the principle of least squares to solve the equations[7].

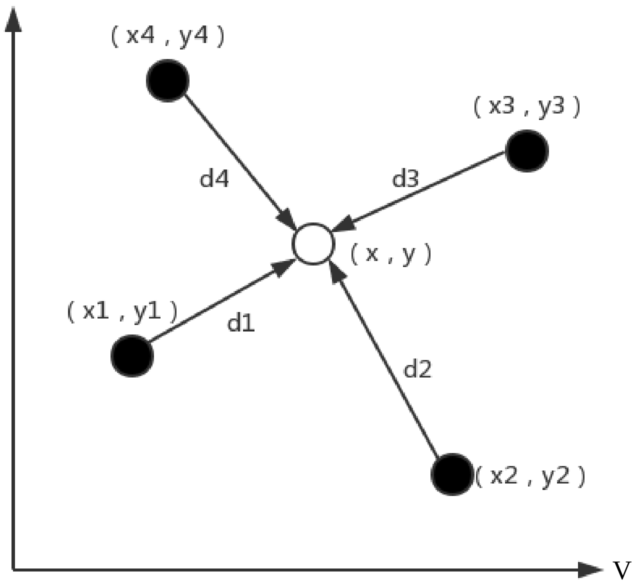

Figure 1: Principle of maximum likelihood estimation

As shown in figure 1, set the label coordinates as (x, y). Given the base stations coordinates, set them respectively as (x_1, y_1), (x_2, y_2), (x_3, y_3) ..., (x_n, y_n). And the measured distance to the label respectively is d_1, d_2, d_3 ..., d_n. Then the following equations can be obtained from the above relation:

$$\begin{cases} (x_1 - x)^2 + (y_1 - y)^2 = d_1^2 & (1) \\ (x_2 - x)^2 + (y_2 - y)^2 = d_2^2 & (2) \\ (x_3 - x)^2 + (y_3 - y)^2 = d_3^2 & (3) \\ \vdots & \\ (x_n - x)^2 + (y_n - y)^2 = d_n^2 & (n) \end{cases}$$

Subtract (n) from each c to get the following equations.

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

The above equations can be converted into matrix equations **Ax**=**b**. Then the following relation can be obtained.

$$\boldsymbol{A} = -2 \times \begin{bmatrix} (x_1 - x_n) & (y_1 - y_n) \\ (x_2 - x_n) & (y_2 - y_n) \\ \cdots\cdots & \cdots\cdots \\ (x_{n-1} - x_n) & (y_{n-1} - y_n) \end{bmatrix}, \boldsymbol{x} = \begin{bmatrix} x \\ y \end{bmatrix},$$

$$\boldsymbol{b} = \begin{bmatrix} d_1^2 - d_n^2 - x_1^2 + x_n^2 - y_1^2 + y_n^2 \\ d_2^2 - d_n^2 - x_2^2 + x_n^2 - y_2^2 + y_n^2 \\ \cdots\cdots \\ d_{n-1}^2 - d_n^2 - x_{n-1}^2 + x_n^2 - y_{n-1}^2 + y_n^2 \end{bmatrix}$$

For the inherent error of the base station positioning sensor, the measured distance has a certain error that is sightless. Thus, the above formulas can be written as: $\mathbf{Ax} + \mathbf{N} = \mathbf{b}$. In the formula, N is an unknown (n-1) dimensional distance-measuring error vector. The principle of least square method is applied to minimize the error vector N. The following formula can be deduced.

$$Q(x) = \|\mathbf{N}\|^2 = \|\mathbf{b} - \mathbf{Ax}\|^2$$

Then, the partial of Q of x with respect to x is taken and seted equal to 0. So, the above formula is equal to the following.

$$\hat{\mathbf{x}} = (\mathbf{A}^{\mathrm{T}}\mathbf{A})^{-1}\mathbf{A}^{\mathrm{T}}\mathbf{b}\text{。}$$

2.2 Maximum likelihood estimation

Min-Max localization algorithm is a simple positioning algorithm with low power consumption and simple calculation. In this paper, reference node is replaced by the base station, and blind node is replaced by the label[8].

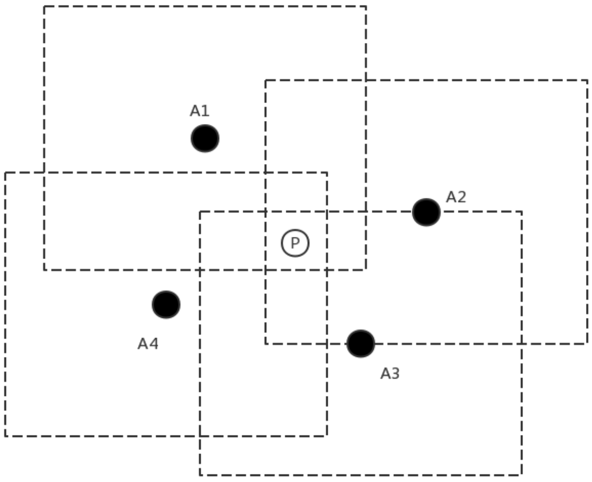

Figure 2: Principle of Min-Max localization algorithm

As shown in figure 2, Ai are base station and P is label. Set the base stations coordinate respectively as (x_1, y_1), (x_2, y_2), (x_3, y_3) ..., (x_n, y_n). And the measured distance to the label respectively is d1, d2, d3 ..., dn. Then take Ai as the center and 2di as the side length to form multiple rectangular ranges. Set the ranges as Bi respectively. And following formula can be deduced: $\mathrm{P} \in \bigcap_{i=1}^{i} B_i$

$$\mathrm{B}_i \cap B_j = \left[\max\left((\mathrm{x}_i - d_i), (\mathrm{x}_j - d_j)\right), \min\left((\mathrm{x}_i + d_i), (\mathrm{x}_j + d_j)\right)\right] \times \left[\max\left((\mathrm{y}_i - d_i), (\mathrm{y}_j - d_j)\right), \min\left((\mathrm{y}_i + d_i), (\mathrm{y}_j + d_j)\right)\right]$$

This leads to a conclusion.

$$\mathrm{P} \in [x_{max} - r, x_{min} + r] \times [y_{max} - r, y_{min} + r]$$

There is the following relation in the above formula.

$$\begin{aligned} \mathrm{x_{max}} &= \max(\mathrm{x_1}, \mathrm{x_2}, \mathrm{x_3}, \dots\dots, \mathrm{x_i}) \\ \mathrm{x_{min}} &= \min(\mathrm{x_1}, \mathrm{x_2}, \mathrm{x_3}, \dots\dots, \mathrm{x_i}) \\ y_{\mathrm{max}} &= \max(\mathrm{y_1}, \mathrm{y_2}, \mathrm{y_3}, \dots\dots, \mathrm{y_i}) \\ \mathrm{y_{min}} &= \min(\mathrm{x_1}, \mathrm{y_2}, \mathrm{y_3}, \dots\dots, \mathrm{y_i}) \end{aligned}$$

Finally, the coordinates of P can be estimated as the center of the intersection of Bi.

$$(\hat{x}, \hat{y}) = (\frac{x_{max} + x_{min}}{2}, \frac{y_{max} + y_{min}}{2})$$

3. UNMANNED SHIP POSITIONING ALGORITHM

This paper uses Base station ranging to reach the requirements of the ranging phase. In this paper, we use maximum likelihood estimation under special conditions to determine the coordinates of the base stations and establish the base station coordinates system. Then the Min-Max positioning algorithm, which uses base stations and tags to replace reference nodes and blind nodes, is applied to the coordinate system based on the base station coordinates.

Set the base stations' coordinates as $A_0(x_0, y_0)$, $A_1(x_1, y_1)$, $A_2(x_2, y_2)$, $A_3(x_3, y_3)$ respectively. Firstly, this paper takes A_0 as the origin of coordinates and establish the base station positioning coordinate system. Then, set A_1 on the X-axis. This is to say, x0=y0=y1=0. Set the coordinate of label P as (x, y), $A_0A_1=d_1$, $A_0A_2=d_2$, $A_0A_3=d_3$, $A_1A_2=d_4$, $A_1A_3=d_5$, $A_2A_3=d_6$, $A_0Q=d_{0q}$, $A_1Q=d_{1q}$, $A_2Q=d_{2q}$, $A_3Q=d_{3q}$. Then the following equations can be obtained from the above relation:

$$\begin{cases} \mathrm{x}_1^2 + \mathrm{y}_1^2 = d_1^2 & (1) \\ \mathrm{x}_2^2 + \mathrm{y}_2^2 = d_2^2 & (2) \\ \mathrm{x}_3^2 + \mathrm{y}_3^2 = d_3^2 & (3) \\ (x_1 - x_2)^2 + (y_1 - y_2)^2 = d_4^2 & (4) \\ (x_1 - x_3)^2 + (y_1 - y_3)^2 = d_5^2 & (5) \\ (x_3 - x_2)^2 + (y_3 - y_2)^2 = d_6^2 & (6) \end{cases}$$

This paper applies maximum likelihood algorithm to calculate the coordinate of A3 by combining (3) and (5). Let's do the same thing for A2 by combining (2), (4) and (6).

Finally, according to the known base station coordinates and the distances between the tag and each base station, the tag coordinates can be solved by the modified Min-Max positioning algorithm.

4. EXPERIMENT

In order to verify the stability and accuracy of the positioning algorithm, two experiments are designed in this paper. This paper takes LE as the positioning accuracy criteria and LE $= \sqrt{(\hat{x} - x)^2 + (\hat{y} - y)^2}$[5].

Experimental method- Four base stations are placed in a rectangle on the ground. For the first time, the base station is placed in a rectangle of 9.838m×7.958m (hereinafter referred to as the small rectangle). For the second time, the base station is placed in a rectangle of 22.8m ×5.838m (hereinafter referred to as the big rectangle). The stability and accuracy of the algorithm are analyzed by measuring multiple sets of data based on the coordinates of three points measured in advance.

Experimental objective-The experimental objective is to verify the accuracy and stability of the positioning algorithm.

Part of the measurement data is shown in the figures and tables below:

Table 1: Part of the measurement data of big rectangle

Number	experimental data (unit: m)				
	$\hat{x}$	$\hat{y}$	x	y	LE
1	0.45	5.21	0.68	6.17	0.987
2	0.41	5.24	0.68	6.17	0.968
3	0.46	5.3	0.68	6.17	0.897
4	0.43	5.31	0.68	6.17	0.896
5	0.45	5.24	0.68	6.17	0.958
6	5.13	3.41	4.85	3.80	0.48
7	4.87	3.38	4.85	3.80	0.42
8	4.87	3.38	4.85	3.80	0.42
9	4.9	3.4	4.85	3.80	0.403
10	5.08	3.41	4.85	3.80	0.453
11	2	2.04	1.67	1.78	0.42
12	1.96	2.03	1.67	1.78	0.383
13	1.91	2.02	1.67	1.78	0.339
14	1.92	2	1.67	1.78	0.333
15	1.93	2.03	1.67	1.78	0.361

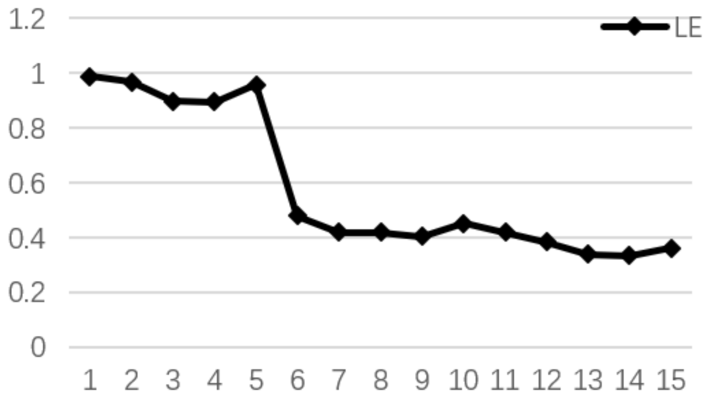

Figure 3: LE of big rectangle

Table 2: Part of the measurement data of small rectangle

Number	experimental data (unit: m)				
	$\hat{x}$	$\hat{y}$	x	y	LE
1	1.48	6.19	0.68	6.17	0.8
2	1.48	6.19	0.68	6.17	0.8
3	1.47	6.18	0.68	6.17	0.79
4	1.49	6.17	0.68	6.17	0.81
5	1.5	6.2	0.68	6.17	0.821
6	4.88	4.38	4.85	3.80	0.581
7	4.9	4.37	4.85	3.80	0.572
8	4.88	4.39	4.85	3.80	0.591
9	4.91	4.36	4.85	3.80	0.563
10	4.87	4.39	4.85	3.80	0.59
11	2.04	2.93	1.67	1.78	1.208
12	2.03	2.95	1.67	1.78	1.224
13	1.99	2.9	1.67	1.78	1.165
14	2	2.93	1.67	1.78	1.196
15	2.01	2.89	1.67	1.78	1.161

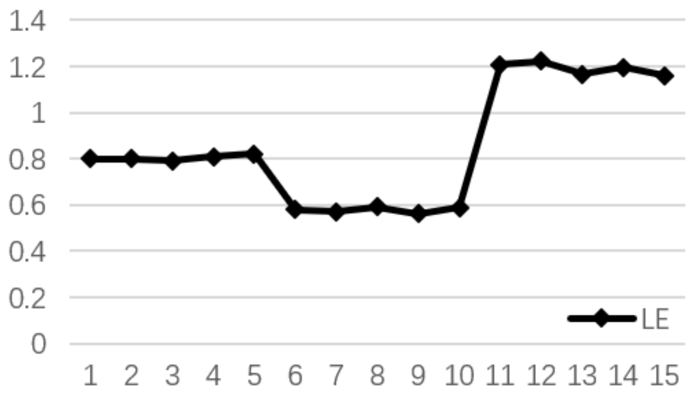

Figure 4: LE of small rectangle

According to above data, the following conclusions can be clearly obtained: 1. The algorithm is fully applicable to the positioning requirements within a short distance and it has achieved the purpose of the algorithm design; 2. Within a certain distance, when the positioning range increases, the positioning accuracy of the algorithm can be improved to a certain extent. In the above data, the positioning error can be stable below 1.5m; 3. The maximum fluctuation of positioning error at the same point is 0.091m. It means that the algorithm has good stability and no large fluctuation.

5. CONCLUSIONS

In this paper, a positioning algorithm based on the maximum likelihood algorithm and Min-Max positioning algorithm is proposed, which can meet the needs of short range positioning. Compared with GPS, Beidou navigation and other popular civil positioning systems, this algorithm has lower cost and higher accuracy.

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