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A Localization Algorithm for Underwater Wireless Sensor Networks Based on Ranging Correction and Inertial Coordination

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Abstract

Node localization is the basic task of underwater wireless sensor networks (UWSNs). Most of the existing underwater localization methods rely on ranging accuracy. Due to the special environment conditions in the ocean, beacon nodes are difficult to deploy accurately. The narrow bandwidth and high delay of the underwater acoustic communication channel lead to large errors. In order to reduce the ranging error and improve the positioning accuracy, we propose a localization algorithm based on ranging correction and inertial coordination. The algorithm can be divided into two parts, Range Correction based Localization algorithm (RCL) and Inertial Coordination based Localization algorithm (ICL). RCL uses the geometric relationship between the node positions to correct the ranging error and obtain the exact node position. However, when the unknown node deviates from the deployment area with the movement of the water flow, it cannot communicate with enough beacon nodes in a certain period of time. In this case, the node uses ICL algorithm to combine position data with motion information of neighbor nodes to update its position. The simulation results show that the proposed algorithm greatly improves the positioning accuracy of unknown nodes compared with the existing localization methods.

Keywords: wireless sensor networks, underwater, node location, ranging correction, inertial coordination

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1. Introduction

Recently, underwater wireless sensor networks (UWSNs) have attracted much attention and provided sufficient technical support to many application fields, such as ocean environment monitoring, natural disaster prevention and military defense [1-2]. Localization technology is one of the key technologies of UWSNs [3-6]. However, due to the complex underwater environment, the ground node location method cannot be directly applied to UWSNs [7], UWSNs should use different underwater localization methods.

UWSNs localization mainly faces the following difficulties: (1) In UWSNs, the underwater acoustic channel has special characteristics such as narrow bandwidth, high propagation delay, and severe multipath scattering [8-9], which lead to large ranging error and greatly affect the accuracy of the ranging-based localization algorithm. (2) Because the deployment of underwater nodes is large, and the number of beacon nodes is small and the distribution is sparse, the localization algorithm relying on high-density beacon nodes cannot be used. (3) More importantly, all underwater nodes constantly moving by the influence of ocean currents and tides. The localization algorithm must consider the moving characteristics of the nodes [10-11]. These ubiquities in the ocean environment make positioning underwater nodes a challenging task.

Existing underwater sensor networks localization algorithms, such as the multilateral positioning algorithm [12-13]. It is centered on the beacon node, and collects multiple circles with a communication distance as a radius to obtain the coordinates of the node. Two-Phase Time Synchronization-Free Localization Algorithm (TP-TSFLA) [14] uses the geometric relationship between nodes to locate. The Sensor Localization Algorithms (SLA) [15] uses iterative methods to extend the intersection area to the surrounding area to calculate the coordinates of the unknown node. Although these positioning algorithms are theoretically feasible, there are still large positioning errors in practice. The Global Node Selection (GNS) algorithm [16-17] is a typical algorithm for inertial navigation and nodes location update. The strategy of the algorithm is to assume that the node knows the information of the entire network, but due to the mobility of the UWSN nodes and limited storage capacity, this strategy cannot solve the UWSN underwater target tracking problem. There are also a lot of researches on the underwater target tracking problem of UWSN in the literature [18-19], but these results are based on raw measurements, but considering the limited energy and communication bandwidth of UWSN, the original measurement not applicable to UWSN.

In view of the above problems, we analyze the error source of UWSNs in detail. For the range based localization algorithm, the most important error source is the ranging error. At present, most of the existing underwater localization algorithms do not take this into account. They limited to the error caused by nodes movement. In this paper, we design a Range Correction based Localization algorithm (RCL). The geometric relationship between the node positions is used to reduce the ranging error, and the exact position of the node is obtained. This algorithm can correct most of the ranging errors and improve the localization accuracy. For the case that sparse deployment leads to insufficient beacon nodes, we design an Inertial Coordination based Localization algorithm (ICL) based on the movement law of underwater nodes under the influence of ocean currents. The position of the node is obtained based on the inertial navigation position data combined with the motion information of the neighbor nodes. And the simulation results show that the designed algorithm is superior to other existing underwater sensor networks localization algorithms in accuracy and practicability.

The remaining portion of this paper is organized as follows: Section 2 summarizes the related works. In Section 3, we introduce the network model and proposed the range correction localization algorithm and inertial cooperative localization algorithm. Simulation results are reported in Section 4. We conclude our work in Section 5 with a discussion of future research works.

2. Related Work

Underwater node localization technology is one of the most critical technologies in underwater sensor network applications. Without node location information, the collected data has no meaning [20-21]. However, the localization of underwater sensor nodes is affected by many factors such as underwater environment and underwater acoustic communication which makes existing WSN localization algorithms can not be applied to underwater [22-25].

Existing sensor network location schemes could be divided into two groups [26]: range-based and range-free. Rang-based methods need to obtain the distance between the unknown node and the adjacent known node [27]. Typical techniques mainly include Time of Arrival (TOA) [28], Time Difference of Arrival (TDOA) [29], Angle of Arrival (AOA) [30], and Received Signal Strength Indicator (RSSI) [31]. For example, the Underwater Positioning Scheme (UPS) algorithm [32] uses TDOA technology for localization. The algorithm does not need time synchronization, but nodes outside the coverage of four nodes cannot be located, which reduces the localization coverage of the UPS. The Dive and Rise Localization (DNRL) algorithm [33] uses the one-way TOA method for ranging, which enables “quiet” localization, but requires precise time synchronization between nodes. Multi-stage Localization (MSL) [34] is an improvement to the DNRL scheme. The ranging is also a one-way TOA method and the mobility of underwater nodes takes into account, but it also requires precise time synchronization. The AUV-aided Localization (AAL) algorithm [35] is an underwater autonomous aircraft assisted localization scheme. It uses two-way TOA to measure distance, does not require time synchronization, but the communication overhead is large and the localization accuracy is limited by Autonomous Underwater Vehicle (AUV) ranging accuracy. The There-Dimensional Underwater Localization (DUL) [36] algorithm uses two-way TOA ranging, which does not require time synchronization, but the communication delay of this scheme is longer. As time goes by, the ranging error accumulates, which affects the localization accuracy of algorithm.

Rang-free methods do not need to measure the distance between nodes, but the distance of the unknown node is calculated by the connection degree between the unknown node and the surrounding nodes. For example, the Localization with Directional Beacons (LDB) algorithm [37] uses AUV to locate underwater nodes, which is mainly used in static hydrological environments. The communication overhead is small but the accuracy mainly depends on the signal transmission frequency of AUV. The Scalible Localization with Mobility Prediction (SLMP) algorithm [38] can be applied to a dynamic hydrological environment. Both the anchor node and the unknown node estimate the position according to their own motion pattern and previous coordinates [39], but the performance of the algorithm is affected by the localization period and the motion prediction model. Compared with the ranging-based localization algorithms, the rang-free localization algorithms have lower localization accuracy.

Below we use the form of a table to compare the performance of some commonly used underwater wireless sensor network localization algorithms. As shown in **Table 1**.

Table 1. Localization algorithm comparison

Algorithm name	**Distributed/ centralized**	**Based on estimation/ predicting**	**Anchor type**	**Ranging method**	**Communica-tion mode**	**Time synchro-nization**
UPS[32]	distributed	Based on estimation	Static anchor node	TDOA ranging	silence	No need
DNRL[33]	distributed	Based on estimation	Mobile anchor node	One-way TOA ranging	silence	need
MSL[34]	distributed	Based on estimation	Mobile anchor node	One-way TOA ranging	Iteration	need
AAL[35]	distributed	Based on estimation	AUV	Two-way TOA ranging	silence	No need
LDB[37]	distributed	Based on estimation	AUV	No need to measure distance	silence	No need
SLMP[38]	distributed	Based on predicting	Buoy node, anchor node, reference node	One-way TOA ranging	Iteration	need

As discussed above, rang-based localization algorithms has higher accuracy than rang-free localization algorithms, but ranging error will lead to localization error, and the nodes outside the beacon node coverage cannot be located. In addition, such algorithms have higher requirements on the node performance. In this paper, by studying the characteristics of underwater sensor networks and considering the various influencing factors in the underwater node localization process, RCL and ICL algorithm is proposed. Compared with the existing algorithms, the algorithm uses the geometric relationship between nodes to reduce the ranging error and improve the positioning accuracy. In the case that the node deviates from the beacon coverage area, we locate the unknown node in combination with the moving state of the neighbor node. The ranging correction and inertial cooperation mode are different from the existing localization algorithm and have high practical value.

3. Algorithm design

In this section, we propose a localization algorithm for underwater wireless sensor networks based on ranging correction, and propose an inertial cooperative positioning mechanism in the case of insufficient beacons.

3.1 RCL Algorithm

Underwater acoustic communication greatly influenced by the underwater pressure, temperature salinity and so on that leads to large ranging error, which is the main error source of localization algorithms. In order to improve the localization accuracy, we adopt the underwater sensor network localization algorithm based on ranging correction, which mainly includes two steps: The first step is the pre-localization based on the simple multilateral localization algorithm to get the rough position of the node. The second step is the precise localization based on the ranging correction, using the geometric relationship between the nodes to reduce the ranging error and calculate the exact position of the node.

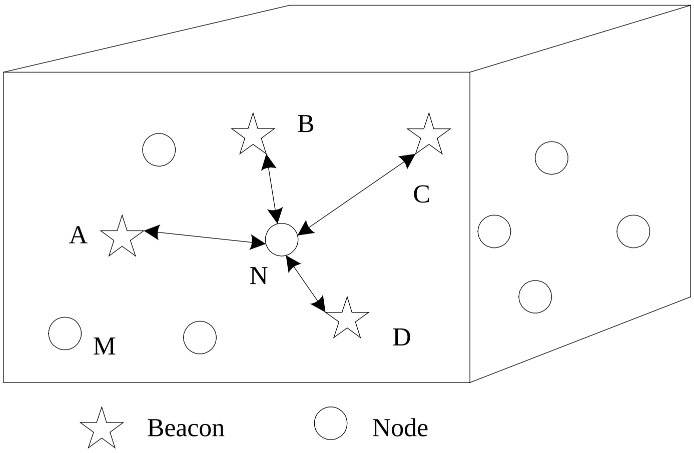

Fig. 1. Pre-localization process

As shown in **Fig. 1**, the positions of beacons A, B, C, and D are known, and other nodes need to be localized by beacons. In the pre-localization phase, node N emits a localization request, and beacons A, B, C, and D receive the localization request, and send their coordinates (x_A, y_A, z_A) , (x_B, y_B, z_B) , (x_C, y_C, z_C) and (x_D, y_D, z_D) to node N. Node N uses existing ranging algorithms (such as TOA, TDOA, etc.) to calculate the distance between it and beacons A, B, C, and D, denoted as d_A, d_B, d_C , d_D, and then uses the principle of multilateral localization algorithm:

$$qX = g \tag{1}$$

Among them,

$$q = \begin{bmatrix} 2(x_A - x_D) & 2(y_A - y_D) & 2(z_A - z_D) \\ 2(x_B - x_D) & 2(y_B - y_D) & 2(z_B - z_D) \\ 2(x_C - x_D) & 2(y_C - y_D) & 2(z_C - z_D) \end{bmatrix}$$

$$g = \begin{bmatrix} x_A^2 - x_D^2 + y_A^2 - y_D^2 + z_A^2 - z_D^2 + d_D^2 - d_A^2 \\ x_B^2 - x_D^2 + y_B^2 - y_D^2 + z_B^2 - z_D^2 + d_D^2 - d_B^2 \\ x_C^2 - x_D^2 + y_C^2 - y_D^2 + z_B^2 - z_D^2 + d_D^2 - d_C^2 \end{bmatrix}$$

$$X = \begin{bmatrix} x_{N1} \\ y_{N1} \\ z_{N1} \end{bmatrix}$$

The coarse coordinate N1 (x_{N1}, y_{N1}, z_{N1}) of node N can be calculated by Eq. (1).

There are many factors affecting the localization accuracy, and the ranging error is the biggest influencing factor. This is due to the complex and variable underwater environment, the underwater sound velocity has a vertical distribution characteristic, which changes with the depth, salinity, temperature and other factors, resulting in a large ranging error [40]. In order to make the localization results more accurate, we propose a precise localization algorithm based on the ranging correction, which is to correct the result of the pre-localization and obtain a more accurate node position.

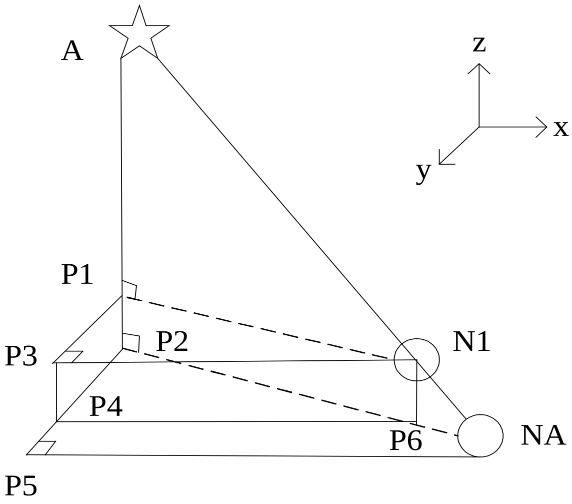

Fig. 2. Ranging correction diagram

Usually, underwater nodes are equipped with a pressure sensor to obtain their z-axis exact coordinates. Taking beacon A as an example, the ranging error causes node position NA (x_{NA}, y_{NA}, z_{NA}) with accurate z-axis coordinates to be located on the line (or extension) of ANA, and the computed position is N1, as shown in **Fig. 2**. Make a vertical line AP1 from the position of beacon A to the plane of xy axis. Then make a vertical line from the calculated node position N1 to AP1, the foot point is P1. And then, the node position NA with the exact z-axis coordinates makes a vertical line to AP2, the foot point is P2. The $\Delta \mathrm{AP1N1}$ and $\Delta \mathrm{AP2NA}$ are similar triangles, we could get

$$\frac{AP1}{AP2}=\frac{AN1}{ANA}=\frac{P1N1}{P2NA} \tag{2}$$

Similarly, making a vertical line N1P3 from N1 to the plane of the yz axis, the foot point is P3, making a vertical line NAP5 from NA to the plane of the yz axis, the foot point is P5, making a vertical line P3P4 from P3 to the plane of the xy axis, the foot point is P3, and making a vertical line N1P6 from N1 to the plane of the xy axis, the foot point is P6. $\Delta \mathrm{P2P4P6}$ and $\Delta \mathrm{P2P5NA}$ are similar triangles, we could get

$$\frac{P2P4}{P2P5}=\frac{P4P6}{P5NA}=\frac{P2P6}{P2NA} \tag{3}$$

Since $P1N1 = P2P6$, substitute it to Eq. (3),

$$\frac{P2P4}{P2P5}=\frac{P4P6}{P5NA}=\frac{P1N1}{P2NA} \tag{4}$$

From solve Eqs (2) and (4), we could get

$$\frac{AP1}{AP2} = \frac{P2P4}{P2P5} = \frac{P4P6}{P5NA} \tag{5}$$

which is,

$$\frac{z_{N1} - z_A}{z_{NA} - z_A} = \frac{y_{N1} - y_A}{y_{NA} - y_A} = \frac{x_{N1} - x_A}{x_{NA} - x_A} \tag{6}$$

The coordinate (x_{NA}, y_{NA}) of position NA could be solved from Eq. (6), and the z-axis coordinate has been measured by the pressure sensor, so the coordinate of NA is (x_{NA}, y_{NA}, z_{NA}) .

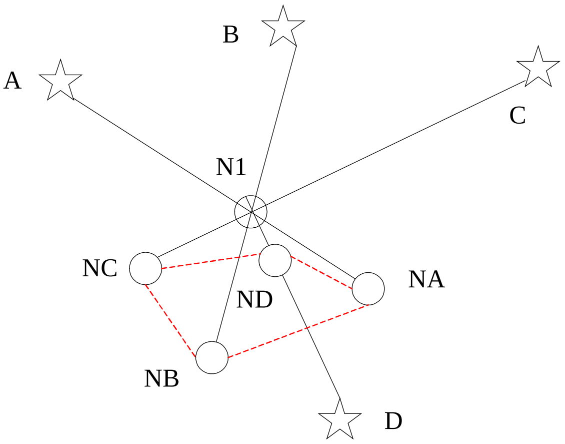

Fig. 3. Ranging correction localization

Repeating the above process for the beacons B, C, and D, the coordinates of NB, NC, and ND can be obtained, recorded as (x_{NB}, y_{NB}, z_{NB}), (x_{NC}, y_{NC}, z_{NC}) and (x_{ND}, y_{ND}, z_{ND}), as shown in **Fig. 3**. Next, the exact position (x_N, y_N, z_N) of the node N is calculated. Where $z_N = z_{NA} = z_{NB} = z_{NC} = z_{ND}$, the xy axis coordinates of node N can be obtained by the centroid algorithm.

$$\begin{cases} x_N = \dfrac{x_{NA} + x_{NB} + x_{NC} + x_{ND}}{4} \\ y_N = \dfrac{y_{NA} + y_{NB} + y_{NC} + y_{ND}}{4} \end{cases} \tag{7}$$

According to above method, the nodes in the network could be located one by one. When the number of beacons is insufficient, the nodes that have completed localization can serve as beacons to assist localization calculation.

3.2 ICL Algorithm

Underwater nodes are inevitably moved under the influence of currents and tides. Therefore, the localization algorithm has to re-run at regular intervals to update the node positions.

During the movement of the node, it may deviate from the deployment area in a certain period of time, resulting in failure to communicate with enough beacons. At this time, we adopt a cooperative localization method, in which the inertial navigation position data is combined with the motion information of neighbor nodes to obtain the node position.

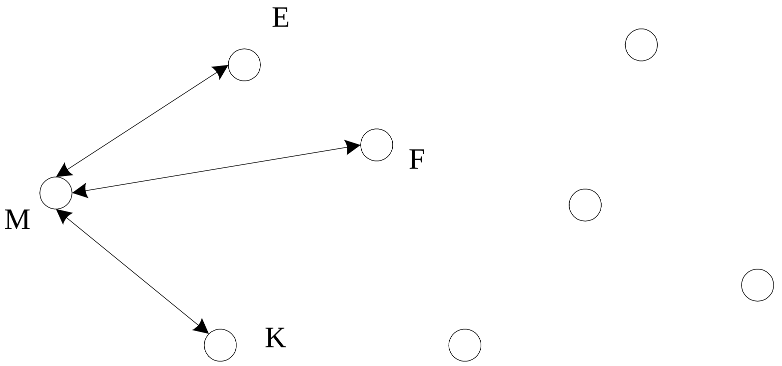

Fig. 4. Inertial cooperative localization diagram

As shown in **Fig. 4**, the node M sends a localization request, and only obtains replies from the neighbor nodes E, F, and K. As the number of replies is less than the minimum number of beacons required for calculation (at least 4 beacons are required for 3D underwater localization), it enters the inertial cooperative localization mode. The node M calculates the position offset $(\Delta x_M, \Delta y_M, \Delta z_M)$ by using the position data and time obtained by the previous two times of localizations,

$$\begin{cases} \Delta x_M = \dfrac{x_M(n) - x_M(n-1)}{T(n) - T(n-1)} \\ \Delta y_M = \dfrac{y_M(n) - y_M(n-1)}{T(n) - T(n-1)} \\ \Delta z_M = \dfrac{z_M(n) - z_M(n-1)}{T(n) - T(n-1)} \end{cases} \tag{8}$$

where $x_M(n), y_M(n)$, $z_M(n)$ are the coordinates of the nth localization, and $T(n)$ is the time of the nth localization, n=1, 2....

At the same time, node M sends a co-location request, the nodes E, F, K receive the request, calculate their position offsets $(\Delta x_E, \Delta y_E, \Delta z_E), (\Delta x_F, \Delta y_F, \Delta z_F), (\Delta x_K, \Delta y_K, \Delta z_K)$ and send them to node M, node M calculates the distances d_E, d_F, d_K from it to nodes E, F, and K.

The underwater node movement has consistency in a short time [41], and its current position offset $(\Delta x, \Delta y, \Delta z)$ can be derived by using its last position offset and the neighbor nodes' position offsets,

$$\begin{cases} \Delta x = w_M \Delta x_M + w(d_E)\Delta x_E + w(d_F)\Delta x_F + w(d_K)\Delta x_K \\ \Delta y = w_M \Delta y_M + w(d_E)\Delta y_E + w(d_F)\Delta y_F + w(d_K)\Delta y_K \\ \Delta z = w_M \Delta z_M + w(d_E)\Delta z_E + w(d_F)\Delta z_F + w(d_K)\Delta z_K \end{cases} \tag{9}$$

where w is a weight that inversely proportional to the distance between the nodes, $w_M + w(d_E) + w(d_F) + w(d_K) = 1$.

Let $w(d_E) = \dfrac{L}{d_E}$, $w(d_F) = \dfrac{L}{d_F}$, $w(d_K) = \dfrac{L}{d_K}$, we could get,

$$w_M + (\frac{1}{d_E} + \frac{1}{d_F} + \frac{1}{d_K})L = 1 \tag{10}$$

w_M can be adjusted according to the actual situation, substitutes it to Eq. (10) to solve L, we can get $w(d_E)$, $w(d_F)$, $w(d_K)$.

According to the number of beacons could communicate to the node, the above formula can be written as

$$\begin{cases} \Delta x = w_M \Delta x_M + \sum w(d_i)\Delta x_i \\ \Delta y = w_M \Delta y_M + \sum w(d_i)\Delta y_i \\ \Delta z = w_M \Delta z_M + \sum w(d_i)\Delta z_i \end{cases} \tag{11}$$

among them, $w + \sum w(d_i) = 1$.

Node M can calculate its current position based on the position offset (x_M, y_M, z_M),

$$\begin{cases} x_M = [T - T(n)]\Delta x + x_M(n) \\ y_M = [T - T(n)]\Delta y + y_M(n) \\ z_M = [T - T(n)]\Delta z + z_M(n) \end{cases} \tag{12}$$

where T is the current localization time.

When the node is able to communicate with sufficient number of beacons, it exits the ICL and uses RCL again.

4. Simulations

In this section, we did experiments to analyze RCL and ICL algorithm. Based on the actual environment in the ocean, we use the MATLAB2016a platform to simulate the deployment and movement of nodes in the sea. The time for the node to send information is 0.1s, the seawater temperature and salinity are set to 15℃ and 35‰ respectively, and the communication radius is 150m. The propagation speed of underwater acoustic waves is listed according to the underwater channel:

$$c = 1449.30 + 4.6T - 0.055T^2 + 0.00029T^3 + (1.34 - 0.01T) \times (S - 35) + 0.16P$$

Where: T represents the temperature of the seawater where the node is located, S represents the salinity of the seawater where the node is located, and P represents the pressure at the depth of the node.

First, the position of the node is calculated by Multilateration algorithm. Then the position obtained by Multilateration algorithm is corrected by RCL algorithm. Second, the results before and after the correction are compared with TP-TSFLA algorithm and SLA algorithm. At the same time, the performance of ICL algorithm in the case of insufficient beacons is analyzed and compared with Mobile Nodes Localization Algorithm (MNLS) [42].

The TP-TSFLA [14] and SLA [15] algorithms were chosen because they have many similarities with the RCL algorithm. The TP-TSFLA algorithm has two phases. The first phase is based on the particle swarm optimization algorithm to obtain the coordinates of the unknown nodes. The second stage is based on the distance-independent positioning algorithm of the circle to locate the unknown nodes left in the first stage. The positioning process of the RCL algorithm also requires two stages, and the geometric relationship between the node positions is used for positioning. The SLA algorithm first calculates the position of the unknown node in the overlapping area of the three beacon nodes, and then uses the iterative algorithm to extend the intersection area to the surrounding area to calculate the coordinates of other unknown nodes. The SLA algorithm has great similarity with the RCL algorithm proposed in this paper. It calculates the coordinates of the unknown node by calculating the intersection area of the beacon node. Through the experiment results, the performance and superiority of the RCL algorithm are analyzed.

The MNLS [42] algorithm is compared with the ICL algorithm because they are both mobile node-based positioning algorithm. The MNLS algorithm first predicts the motion trajectory of the node, and then performs ranging and positioning. ICL algorithm combines the inertial navigation position data with the motion information of the neighbor nodes to obtain the node position. They have great similarities and the comparison between them proves the superiority of our proposed ICL algorithm.

4.1 RCL Simulation

We use simulation software to simulate the distribution state of nodes in the ocean. Four beacon nodes and ten un-located nodes are randomly deployed in the region of $100m*100m*30m$. The distance between the beacon and the un-located node is obtained by TDOA. The time interval for transmitting information is 0.1s, the seawater temperature and salinity are set to $15°C$ and 35‰, respectively, and the communication radius is $150m$.

We first use the Multilateration algorithm to calculate the coordinates of 10 un-located nodes. Then the RCL algorithm is used to correct the obtained result, and compared with the error of Multilateration algorithm, as shown in **Fig. 5**. Then we use the RCL algorithm to compare with TP-TSFLA algorithm and SLA algorithm respectively, as shown in **Fig. 6**.

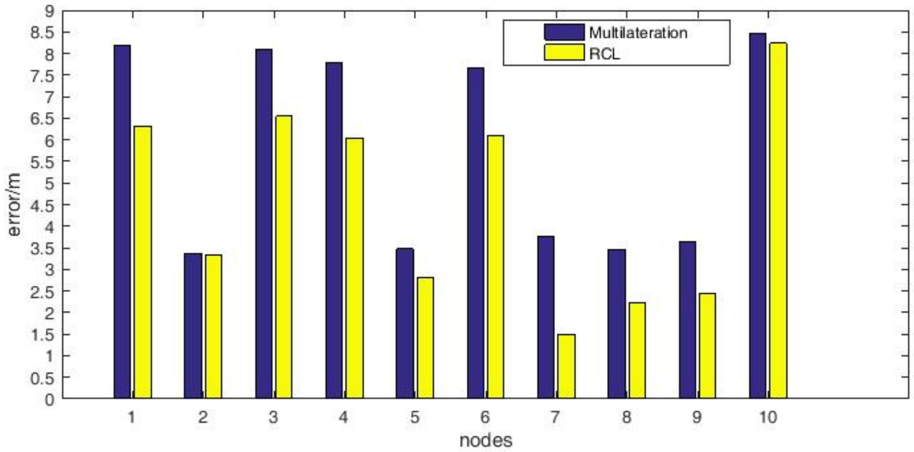

Fig. 5. Errors comparison of RCL and Multilateration

It can be seen from the error comparison results of RCL algorithm and Multilateration algorithm, as shown in **Fig. 5**, the maximum error and the average error of RCL algorithm are much smaller than those obtained directly by the Multilateration algorithm. This is because the error of the Multilateration algorithm is mainly derived from the ranging error, and the calculated rough position will be located on the line where the beacon node and the actual position are located, as shown in **Fig. 2**. The RCL algorithm makes the coarse position on this line closer to the precise position through the geometric relationship between the node positions, improving the position accuracy.

In addition, we can see that the errors of nodes 2, 5, 7, 8, 9 are smaller than other five nodes. This is because the error of the Multilateration algorithm is mainly influenced by the ranging error. The distance from the four beacons is different, and the ranging error is different. When using RCL, if the error calculated by the original algorithm is small, then the correction will be closer to the exact position.

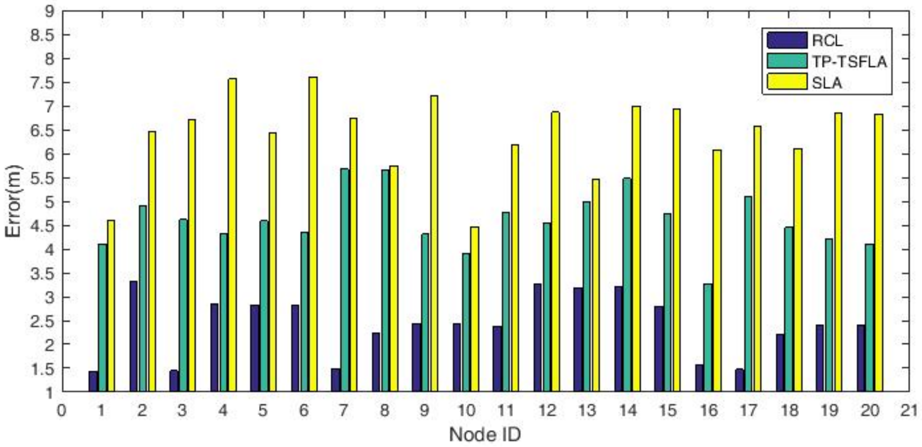

Fig. 6. Localization errors of RCL, TP-TSFLA and SLA

Fig. 6 shows the comparison results of the localization errors of RCL algorithm, TP-TSFLA algorithm and SLA algorithm. The comparison results between RCL algorithm and the two other algorithms can be seen in the figure. The average error of the TP-TSFLA algorithm is 4.583m, the average error of the SLA algorithm is 6.436m, and the average error of the RCL algorithm is 2.618m. The error of RCL algorithm is much smaller than TP-TSFLA algorithm and the SLA algorithm. This is because the errors of TP-TSFLA algorithm and SLA algorithm are derived from the ranging error. However, the RCL algorithm corrects the ranging error by the geometric relationship between the nodes, so its accuracy is greatly improved.

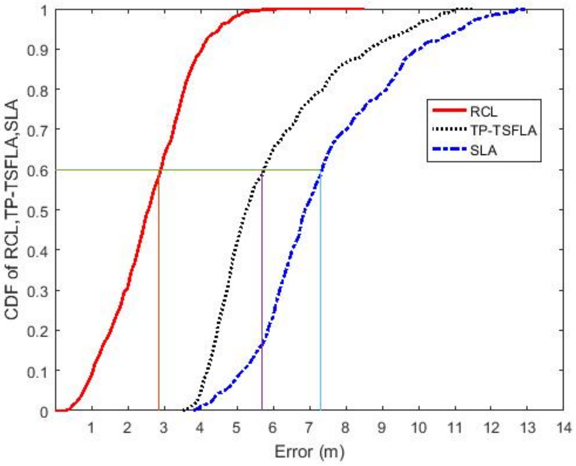

Fig. 7. CDF of localization errors

In order to detect the performance of the RCL algorithm in the case of high-density deployment, we made the localization errors of RCL, TP-TSFLA, and SLA algorithms into CDF graphs. The CDF graphs can visually represent the distribution of errors in a particular area. We randomly deploy 500 nodes in the region of 100m*100m*30m, the depth of these nodes is between 0 and 30 meters from the sea surface. **Fig. 7** shows the CDF of the localization errors of RCL algorithm, TP-TSFLA algorithm and SLA algorithm in the same ocean environment. As can be seen from the figure, the localization errors of RCL algorithm are significantly smaller than that of TP-TSFLA algorithm and SLA algorithm. When the CDF is 0.6, the localization error of the RCL algorithm is between 2.5m and 3m. However, the localization error of TP-TSFLA algorithm is greater than 5.5m, and the localization error of SLA algorithm is greater than 7m. Obviously, in the same ocean environment, the localization error of RCL algorithm is smaller. The above analysis fully proves the superiority of the RCL algorithm.

4.2 ICL Simulation

The ICL algorithm is mainly used when the node deviates from the deployment area, resulting in the inability to communicate with enough beacons in a certain period of time. We still randomly generate 10 unknown nodes and 4 beacon nodes, and then use the RCL algorithm mentioned above to calculate the first two position offsets of nodes, and then calculate the position of unknown nodes according to the ICL algorithm. We set the water flow direction to an angle of 45 degrees with the xy axis, the node moves 30 meters every 10 seconds, and the localization time interval is also 10 seconds. The specific process is shown in **Fig. 8**.

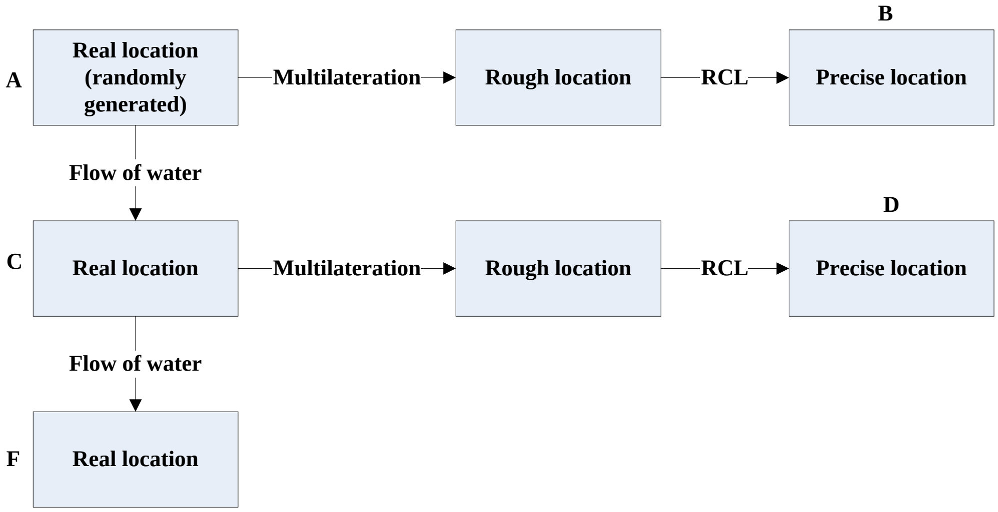

Fig. 8. Inertial coordination localization flowchart

We randomly generate the position A of the node, and then calculate the position B according to RCL algorithm. And then we use software to simulate the flow of water to get the position C. Next, we calculate the position D using RCL algorithm. The position F is obtained by simulating the flow of water according to the position C. From the position B and D, we can get the position offset of the node. From position C we can get the distance from the un-located nodes to the neighbor nodes. Using Eq. (11) and (12) we can calculate the position of the un-located node. We compare the calculated position with the position F to obtain a set of errors, and compare them with the errors of MNLS algorithm as shown in **Fig. 9**.

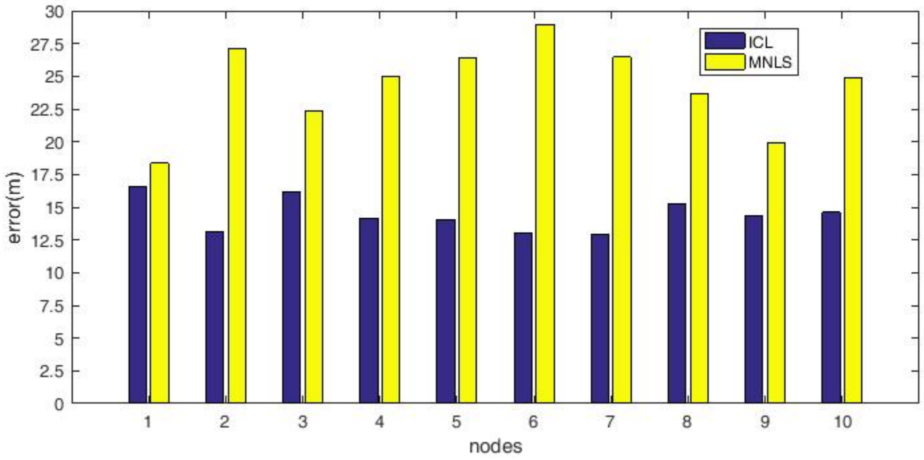

Fig. 9. Errors comparison of ICL and MNLS

It can be seen from the error comparison results in **Fig 9**. The maximum error and average error of ICL algorithm are much smaller than the error obtained by MNLS algorithm.

4.3 Impacts of Nodes' Velocity on Localization Results

In this section, we analyze the impacts of nodes' velocity on localization results. Keeping the original parameter settings, setting 10 unknown nodes and 4 known nodes, the water flow direction is 45 degrees from the XY axis, and the localization time interval is 10 seconds. We change the nodes' velocity, which are 3m/s, 5m/s and 7m/s respectively. The result is shown in **Fig. 10**.

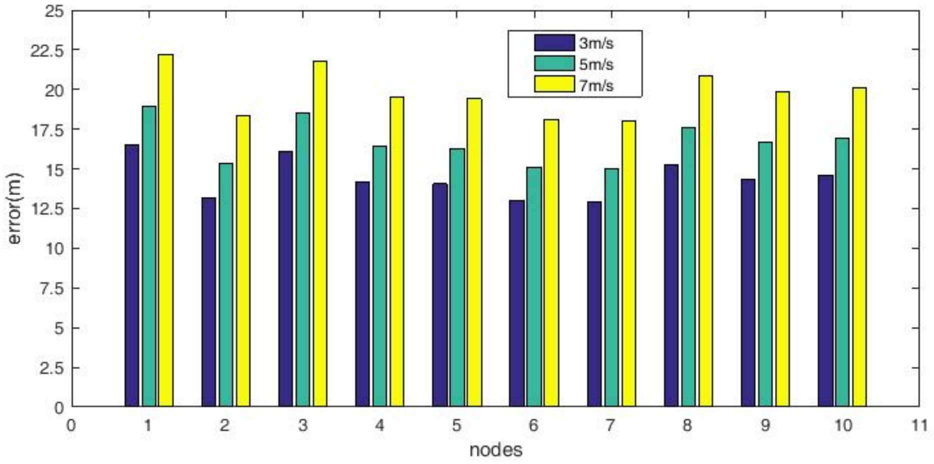

Fig. 10. Effect of the moving speed of the nodes

It can be seen from **Fig. 10** that the nodes' velocities have a certain influence on the error. When the nodes move faster, the errors are greater. But overall, the inertial coordination localization algorithm has relatively small errors.

From simulations, we can see that RCL and ICL algorithm for underwater acoustic sensor networks can reduce the ranging error and improve the position accuracy.

5. Conclusion

In this paper, we propose RCL and ICL algorithm to locate underwater sensor nodes. RCL algorithm corrects the ranging error by the geometric relationship between the node positions, and calculates the exact position of the node. It greatly reduces the cost of investment and the impact of other external environments. ICL algorithm obtains the node position by combined the inertial navigation with the motion information of neighbor nodes to improve positioning accuracy. Compared with TP-TSFLA algorithm, SLA algorithm and MNLS algorithm, RCL and ICL algorithm have significantly higher position accuracy under the same underwater environment, and have good practicability in the underwater wireless sensor network applications. In the future, we will continue to reduce the error rate of sensor network localization based on mobile restricted beacons, expand the applicability of the algorithm to different environments, and do more works on the multidimensional evaluation along different parameters, so that it can be better applied to different kind of underwater networks.

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