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Research on positioning technology in underwater wireless sensor network

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Abstract: Underwater positioning is a very important part of the maritime domain and is of great concern both in the military and civilian spheres. Among them, the underwater wireless sensor network is particularly important because the network is very low cost to build, easy to use, and has many advantages. Nodes need to be used in underwater sensors, and the location information of nodes is particularly important. It is the foundation of the network and one of the current research hotspots. Therefore, many researchers have carried out detailed research on positioning, and improved and studied on the basis of the original positioning algorithm. In this paper, a new localization classification method is studied, and these localization algorithms are compared and analyzed from various aspects. At the same time, this paper elaborates on the positioning and research prospects.

Keywords: Distance measurement; Network architecture; Network scale; Survey; Underwater positioning; Underwater sensor network.

1. Introduction

At present, people have explored land resources a lot, and the technology is quite mature. So researchers are looking more at the exploration of the resources of the ocean. In addition, due to the continuous development of Internet of Things technology, the coordinated development of sea, land and air is an inevitable trend, so it is very necessary to monitor the ocean. However, the underwater environment is very complex and changeable, which brings great challenges to people's exploration of underwater resources. Since the land and underwater environments are different, the monitoring methods used are also different. Against this backdrop, advances in electronics, sensor miniaturization, and low-power technologies have expanded the scope of applications of terrestrial wireless sensor networks (WSNs) to underwater. After testing a variety of networks, the researchers found that the effect of underwater wireless sensor networks is very good. It is used by most researchers and is widely used in environmental monitoring, military fields and underwater data collection. A very basic basis for using wireless sensor networks is the positioning of nodes. The research on positioning algorithms based on UWSNs is also a hot issue. In general, the relevant underwater target localization or tracking algorithm needs to use the position of the sensor node and the data collected by the node to detect, locate or track the underwater target. The positioning accuracy of the sensor node has a great influence on the performance of the underwater target localization or tracking algorithm. Therefore, the research on the positioning algorithm of node position is particularly important. Innovation in positioning algorithms can drive progress and improvement in related fields. [1]

An underwater wireless sensor network consists of multiple independent sensor nodes through which real-time data of a piece of water is monitored. Then, the system selects the matching positioning algorithm and estimates or predicts the approximate position and coordinates of the node through the captured information. In terrestrial sensor networks, there are two commonly used methods, namely GPS and electromagnetic waves. However, the attenuation of these two methods under water is very large, and the requirements for antenna size and transmission power are relatively high. Therefore, there are more acoustic signals and optical signals. Therefore, wireless sensor networks on land are not suitable underwater. After a large number of experiments and explorations, relevant researchers have found that sound and light signals provide suitable conditions for long-distance underwater propagation. It has a low frequency, between 10 Hz and 1 megahertz, which can provide bandwidth, but has a long wavelength. Will the above several wireless communication. The waves are compared, as shown in Table 1.

Table 1. Comparison of Underwater Wireless Communication Waves

Parameters	Acoustic Waves	Optical Waves	EM Waves
Communication Distance	Up to 20 Km	10-100m	100m
Transmit Power	10–100 W	Few Watts	Few mW to Hundreds of Watts
Data Rate	In Kbps	Up to Gbps	Up to 100 Mbps
Cost	High	Low	High

In this paper, the underwater positioning algorithm of underwater wireless sensor network is comprehensively studied, and the main contents are as follows. The second section introduces the basic algorithm based on measurement. In the third section, we introduce the positioning algorithm based on network scale. Finally, in the fourth section, we summarize and present the work on future underwater positioning.

2. Distance Measurement

According to the difference of distance measurement, the positioning algorithm is divided into two categories, namely distance-based positioning algorithm and distanceless positioning algorithm. Two sub-categories of ideas of its classic and latest cutting-edge underwater positioning algorithms are introduced. In addition, we point out the advantages and disadvantages of some algorithms, and

summarize and compare all the presented algorithms.

2.1. Range-Based

Biao et al. [2] proposes a source localization algorithm for UWSNs, which is applicable in both two-dimensional and three-dimensional networks. The specific process is as follows: the sensor node first measures the arrival direction (DOA) of the target signal according to the underwater acoustic sensor array, then obtains the DOA by the MUSIC method, and finally uses the known multi-target maximum likelihood method to locate the sensor node. The simulation results show that the target algorithm is better than the linear least squares method and the nonlinear least squares method.

In the process of underwater acoustic propagation, the geometric expansion and absorption of sound energy by the propagation medium itself leads to a partial loss of wave signal intensity, which affects the accuracy of positioning. In response to this situation, the authors propose a hydroacoustic localization method based on energy (EB) [3]. The process of the algorithm can be roughly divided into two parts. The first part is to measure the signal strength of the target node and calculate the energy on this basis. The other part is to build the transmission model and define the topology of the underwater wireless sensor network to determine the most likely location of the target node. The numerical simulation results show that the algorithm has certain reference value for energy-based underwater node positioning.

2.2. Range-Free

For terrestrial wireless sensor networks, a large number of distance-based node localization algorithms are proposed. Singh and Sharma [4] divide the distanceless localization algorithms of terrestrial wireless sensor networks into two categories: centralized and distributed. The distance-free localization methods of terrestrial wireless sensor networks—triangle approximate point (APIT), DV-hop, multihop, centroid, and gradient, are described in detail. Due to the complex underwater environment, some methods may not be suitable for underwater positioning or need to be improved. This section describes several methods for locating underwater sensor nodes based on distanceless measurements.

Lee and Kim [5] propose a distance-free mobile beacon positioning method. This method is an improved positioning method that uses directional beacons. The sensor network broadcasts and updates the location information of the node by sending beacons, and the sensor node performs autonomous positioning by receiving the beacon message, which does not require interactive communication between nodes. The algorithm first obtains a set of potential possible positions of the destination node, and then performs a weighted average according to this set of possible positions, so as to obtain the position of the destination node and achieve the purpose of positioning. The simulation results show that the positioning error of the algorithm is smaller than that of the beacon message positioning algorithm.

At present, many positioning algorithms are obtained under ideal channel conditions, but they do not take into account that under the influence of limited acoustic signal bandwidth, damaged propagation channel, expensive underwater equipment and other reasons, the channel conditions cannot be ideal. Therefore, a distance-free localization method based on mobile detachable elevator transceiver (DET) and three-dimensional multi-power area positioning (3D-MALS) is proposed in [6]. The elevator transceiver can move vertically in the underwater wireless sensor network, which is based on the fact that each ordinary node can communicate with the transceiver. The Z coordinate (that is, depth information) of all nodes is obtained by the pressure sensor of the node's self-generated configuration, so as to transform the original three-dimensional problem into a two-dimensional problem. Therefore, the algorithm only needs to calculate the maximum distance (outer circle) from the node to the elevator transceiver in the two-dimensional coordinate space, as shown in Figure 1. The simulation results show that the average distance error of the proposed method is lower than that of the two-dimensional area localization scheme [7]. In addition, the authors also propose a distance-free localization method under ideal channel propagation conditions. Compared to the [6] algorithm, this algorithm is ideal.

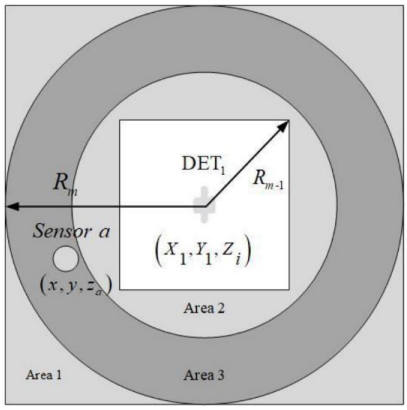


Fig.1 3D-MALS

2.3. The current problem

Table 2. Comparison of Localization Algorithms Based on Distance Measurements

Distance measurement	Method	Accuracy	Energy consumption	Computational complexity	Localization time	Simulation coverage	Communication overhead	Sensor density	Anchor density
Rb and Sy	DOA	Medium	Depend	Medium	Depend	Large	Medium	—	Low
Rb and Sy	EB	Medium	Low	Low	Medium	Large	Low	Low	Low
Rb and Sy	TDOA	High	Large	High	Depend	Small	Large	—	Medium
Rb and Not	RSS	Medium	Large	Low	Short	Small	Large	—	High
Rb and Not	RSS	High	Large	Medium	Depend	Small	Large	—	High
Rb and As	DB/AOA	Depend	Medium	Low	Medium	Small	Medium	High	High
Rb and Not	AOA	High	Large	Medium	Depend	Small	Large	High	High
Rf and As	LoMoB	Depend	Large	Low	Depend	Large	Large	Medium	Low
Rf and As	MALS	Medium	Medium	Low	Medium	Large	Medium	Medium	Low
Rf and As	ALS	Low	Large	Low	Average	Medium	Larger	High	Medium
Rf and As	MALS	Medium	Large	Low	Medium	Large	Large	Medium	Low

Among the above positioning algorithms, the ranging algorithms based on TOA and TDOA need to assume time synchronization and are expensive [8]. However, time synchronization between sensor nodes is difficult to achieve.

In addition, due to the propagation loss of underwater acoustic signals, the estimation error of the RSS-based positioning algorithm is large. In addition, distanceless positioning algorithms do not require measurement of distance and azimuth information. Compared to distance-based algorithms, this algorithm is less affected by the underwater environment and location costs. However, the scheme can only obtain thicker positions. In other words, the accuracy is lower than the distance-based scheme. This article summarizes some positioning methods based on distance measurement, as shown in Table 2. In Table 2, each algorithm has three grades: low, medium and high in different evaluation criteria. According to the simulation results of the algorithm, the dependent value, high, medium and low values of the evaluation criterion are determined.

3. Network Scale

According to the network scale, the positioning algorithm can be divided into two categories: 1) small-scale positioning scheme and 2) large-scale positioning scheme. Two sub-categories of ideas of its classic and latest cutting-edge underwater positioning algorithms are introduced. The existing algorithms are summarized and compared.

3.1. Small-Scale UWSNs

In movable underwater wireless sensor networks, periodic tracking of nodes is required, and the pseudo-random movement of nodes leads to network division, making the localization problem of target nodes more challenging. Islam and Lee [9] propose a two-stage technique to efficiently locate nodes in partitioned networks. Divide the sensor nodes in the network into two types, namely two or more GPS nodes and ordinary sensor nodes. In addition, if the GPS primary node fails, one GPS backup node is responsible. Otherwise, treat the GPS backup node as a normal node. Suppose the normal node is X and the localized node is Y (GPS or localized node). Node X can estimate its absolute coordinates, and only two pieces of information are needed, namely the absolute position of node Y and the relative position of node X relative to node Y. When locating a normal node, its absolute position information is broadcast by a beacon node. The whole localization process can be divided into two stages: 1) reactive phase and 2) initiative phase. The first phase estimates the relative positions of all single- and multi-hop neighbors of the GPS node. In the second phase, it happens iteratively, where divided nodes cluster into one or more clusters based on their communication distance. The cluster header represents the cluster that sent the localization request. Simulation results show that the proposed method has low energy consumption and overhead.

Aiming at the layering effect of aqueous medium, Zhang et al. [10] proposed a unified framework for joint synchronous localization scheme based on Gauss-Newton method (GN-JSL). First, the layering effect is modeled using ray tracing. The layering effect, clock defects, and the location of ordinary nodes are then represented as a unified framework. A corresponding ML estimate is given, which is highly nonlinear and nonconvex. Finally, the Gauss-Newton iterative algorithm is used to solve this problem. In [11], the scheme proposed by the authors adopts hyperbolic event localization algorithm and estimation error normal distribution for modeling and calibration. The method based on ordinary circles is somewhat different from the hyperbola-based method. Typically, two hyperbolas have an intersection point, while circle-based algorithms do not.

3.2. Large-Scale UWSNs

In general, the underwater surveillance area for many military or civilian applications is large. Therefore, large-scale UWNS are needed to effectively monitor it. However, in massive UWSNs, most sensor nodes cannot self-localize due to the inability to communicate directly with multiple anchor nodes or neighbor nodes [12]. In addition, node deployment, communication between nodes, and node mobility in large UWSNs are also relatively challenging. Therefore, positioning algorithms for large UWSNs networks are also emerging.

In [13], a distributed positioning scheme combining three-dimensional Euclidean distance algorithm and recursive position estimation algorithm is proposed. Sensor nodes are divided into three categories: anchor nodes, ordinary nodes and surface buoys. Surface buoys can obtain precise position information from the GPS of the equipment. Anchor nodes can calculate the position of surface buoys by obtaining information about their position. In the process of normal node positioning, sensor nodes are divided into reference nodes and non-positioning nodes. Communication messages are divided into positioning messages and beacon messages. First, mark all anchor nodes as reference nodes and set their confidence value to 1. The non-local sensor nodes select the four non-collinear reference nodes with the highest confidence for position estimation. If the estimation error of the non-local node is small, it can become a new reference node. Otherwise, it cannot be used as a reference node and its location information will not be propagated. The simulation results show that the positioning method has small positioning error and large positioning coverage.

The underwater infinity sensor network uses acoustic and optical signals for data transmission. Due to the introduction of high transmission delay, the phenomenon of conflict data loss is very prominent. Therefore, the influence of media access control (MAC) protocol on positioning algorithm is considered in [14], and a variable-interval ALOHA (VI-ALOHA) protocol based on Poisson distribution is proposed. First, the authors designed a multi-layer positioning framework, as shown in Figure 2. The physical layer implements basic data communication. The data link layer needs to ensure that collisions between multiple nodes are avoided. In the application layer of multi-layer positioning network, the non-synchronous positioning scheme is adopted. In the original positioning scenario, the broadcast interval between the mobile anchor nodes is uniform. Beacon nodes use unmanned underwater vehicles to achieve lifting. However, when an ordinary sensor node is within the communication range of the intersection of two anchor nodes, it may not be able to accept two messages from different anchor nodes. Therefore, this paper analyzes the collision effect of beacon packets. The VI-ALOHA protocol reduces collisions by increasing random space-time. The simulation results show that the VIALOHA protocol is superior to the equispaced ALOHA (EI-ALOHA) protocol.

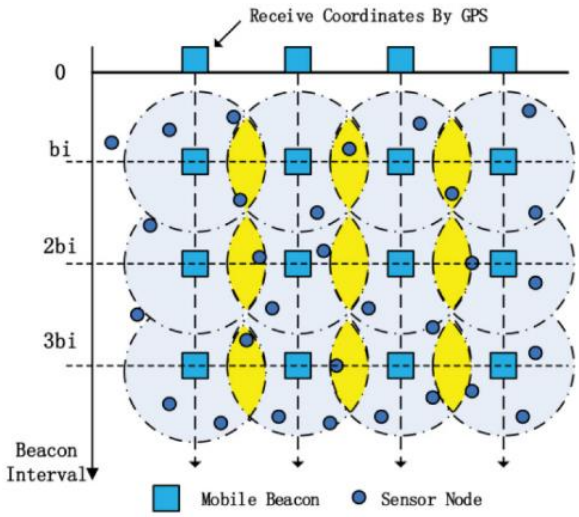


Fig. 2 Underwater localization collision scenario

Table 3. List of Acronyms of Corresponding of Definitions

Acronym	Definition
2D	Two-Dimensional
2SC	Two-Stage Communication
3D	Three-Dimensional
AFLA	Anchor-Free Localization Algorithm
AOA	Angle of arrival
ARTL	Asymmetrical Round-Trip based Localization
AUV	Autonomous underwater vehicle
BSFL	Basic Tine Synchronization-Free Localization
CRLBs	Cramer Rao Lower Bounds
DET	Detachable elevator transceiver
DNR	Dive-and-Rise
DOA	Directional of arrival
EB	Energy-based
EODL	Energy Optimized Distributed Location
GN-JSL	Joint synchronization and localization scheme based on Gauss-Newton
GTRS	Generalized trust region subproblem
HB	Hyperbola-based
HL	Hierarchical Localization
LCDNL	Low-cost Distributed Networked Localization
LLS	Linear least square
LOS	Line-of-sight
LS	Least squares
MAC	Medium access control
MALS-TSF	Mobility-assisted Localization Scheme with Time Synchronization-Free
MASL	Motion-Aware Self-Localization
ML	Maximum likelihood
MP-PSO	Mobility Prediction and a Particle Swarm Optimization algorithm
NLS	Nonlinear least square
OR	Orthogonal Regression
ProLo	Propose an adaptive localization scheme

4. Conclusion

With the increasing interest in the exploration of abundant marine resources, the positioning of underwater nodes based on underwater wireless sensor networks has attracted widespread attention in related fields. Unlike ground-based wireless sensor networks, communication between underwater sensor nodes utilizes sound and light waves due to the particularity and complexity of the underwater environment. In this review, we describe the challenges of acousto-optical communication and underwater positioning. The underwater positioning algorithm based on a new classification method is introduced in detail, namely distance measurement, network scale. The existing algorithm papers are summarized and compared from different perspectives. Table 3 lists some professional-related acronyms.

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