A HIERARCHY NETWORK BASED ON MULTIPLE AUVS AND SONOBUOYS

Xuan Li, Xiaochuan Ma, Shefeng Yan, and Chaohuan Hou

Institute of Acoustics, Chinese Academy of Sciences, Beijing, China

ABSTRACT

A design for underwater network management is proposed in this paper. The underwater network is a tree-shaped construction and has several sub-networks. Being a hierarchy network, every sub-network has a center node that is the gateway of the network, and the sonobuoy is played as center node. Autonomous Underwater Vehicles (AUVs) are the common nodes, and equipped with sonar and underwater acoustic communication modern. The multiple tasks can be assigned to different sub-network, or accomplished cooperatively. With communication and detection range constraints, AUVs move in the survey area to get maximum range that obeys the rule of Voronoi participation algorithm. When some mobile node moves away from the prevenient center, the sub-network should be reconstructed, and the node would join in other nearer sub-network. The flexible and robust construction can be used to cooperative target detection and environment inspection.

Index Terms— underwater network, AUV, hierarchy construction, Voronoi

1. INTRODUCTION

With great applications, underwater network is quite meaningful for underwater resource detection, fishery, environment monitoring and military. It has been the focus of underwater acoustic filed. The UAN (Underwater Acoustic Network) project was established in 2008. AUV plays an important role in the underwater network. It can achieve outperforming mobility, robustness, flexibility to utilize AUVs as nodes of the underwater network. AOSN (autonomous ocean sampling networks), employs multiple AUVs carrying a variety of sensors to measure the ocean parameters at different depths and areas simultaneously.

How to cover the surveillance area by limit nodes (including AUVs and others, such as sonobuoys, surface vehicles, ROVs) is a challenge problem and has been studied by many researchers. It contains several problems, including network topology, nodes placement, mobile nodes paths design, tasks arrangement. In [1][2], the authors suggest a team of AUVs as mobile nodes in underwater network, and present a cooperative adaptive algorithm for the management for asset protecting with communication constraints. For cooperative search and survey by a team of AUVs, several approaches of Synchronization-Based Survey are proposed in [3] and can enable AUVs' surveying with robustness to AUV failures.

In the air and land, distributed network research are more advanced and mature than underwater, and the multiple robotics control problem is suggest to be solved by some diagram algorithms[4]. In [5], a homogeneous network consisted of mobile nodes is designed by Voronoi tessellations. In[6], a scheme of sensor networks redeployment is proposed by using several mobile robots to enhance the network connectivity and the coverage ratio of the surveyed region.

A design for underwater network management is proposed in this paper. The underwater network is a tree-shaped construction and has several sub-networks. Being a hierarchy network, every sub-network has a center node that is the gateway of the network. The idea is similar to the MARTHA Project[7], which is a hierarchical construction and consists of three layers: the Mission layer, the Coordination layer and the Execution layer. Under some rules, such as Euclidean distance, center node's coverage area restrict, operation burden, or task assignment, the common nodes are grouped into several teams. Compared to the other common nodes, the center nodes must get accurate position. For example, the center nodes are heavy AUVs, and the common nodes are light AUVs. With navigation system and large battery, the large AUVs have better performance, including higher positioning accuracy, huger data throughput, and longer work time, etc. However, they are more expensive than light AUVs.

This paper is organized as follows. Section 2 introduces the design ideas, and gives the assumption. In Section 3, more details about the region segment and path control are present. A simulation is given in Section 4. Finally, the conclusions are summarized in Section 5.

2. HIERARCHY DISTRIBUTION

2.1. Approach description

In my design, in order to control cost, the center nodes are sonobuoys, and the common nodes are light AUVs. The exact position coordinates of sonobuoys are gotten by Global Position System (GPS), and then broadcasted to

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the common nodes. Underwater acoustic communication is achieved among the nodes by underwater transducers. Employing electromagnet communication, orders are issued to the sonobuoys, and underwater data is transmitted to the center platform such as a surface vessel. Because of the wind and the ocean flow, the sonobuoys are drifting, so that the center nodes' positions would vary in a small range. AUVs are mobile nodes, and would cruise in the survey area with a speed. They are equipped with sonar and underwater acoustic communication moderns, and can detect underwater targets and communicate with other nodes. Due to the hierarchy construction, the network is flexible and robust. Complex strategy can be achieved. Each sub-network can work independently or cooperatively. The multiple tasks can be assigned to different sub-network, or accomplished together, such as cooperative target detection and environment inspection. The network should adjust the environment and situation. In scenario of area surveillance, AUVs move in the survey area to get maximum cover range with communication and detection range constraints. At first, the sonobuoys are uniformly placed at appropriate positions by aircraft, while AUVs are deployed from any type of surface or air platform. Each AUV monitors a area restricted to the sonar detection range, and the position should be set as Voronoi cell's center.

The initialized positions of the common nodes would impact the formation time of the network, and the positions of the center nodes would impact the coverage ratio. In order to optimum the hierarchy network, the number of center node should be decided by the common nodes and the positions would be computed after the Voronoi cells have been set, so that the sub network's size can succeed to be similar. However, they are usually restricted by the realistic condition.

2.2. Assumption

Let us suppose M AUVs are employed in the network and all of them are in the same depth, and the model is simplified to 2-D. N sonobuoys are uniformly placed at appropriate positions to be the center nodes. Ω denotes the surveillance area, and $\Omega \subset \mathbb{R}^2$. The mission goal is to cover the surveillance area at final step as large as possible, while the stability of network's motion must be ensured, i.e., all of the AUVs's pathes are continuous.

In the paper, we consider as follows,

- R_D^m is the sonar detection range of the m th AUV.
- R_C^m is the maximum communication range of the m th AUV.
- R_P is the minimum distance between any two nodes.

The following assumption are made for the network:

1. Rule 1: strict to the communication distance and sonar detection distance.

   The positions of AUVs and sonobuoys are $\boldsymbol{x}_n$ and $\boldsymbol{y}_n$ respectively, while $\boldsymbol{y}_n$ is nearly const and $\boldsymbol{x}_n$ varies in time. In order to communicate to the center nodes, any AUV must be in the communication range of at least one sonobuoy at any time. The AUVs should be laying on the union of the circles whose centers are the sonobuoys. As a result, all of the AUVs' positions $\boldsymbol{x}_m$ satisfy:

   $$\boldsymbol{x}_m \in \bigcup_{n=1}^{N} C_n, \tag{1}$$

   while $C_n = \{\boldsymbol{x} \in \mathbb{R}^2 | \|\boldsymbol{x} - \boldsymbol{y}_n\| < R_C\}$

2. Rule 2: keep away from any other nodes at least at a distance R_p in order to avoid collision.

   When the nodes are moving, they should maintain a protection distance from any other AUVs and sonobuoys:

   $$\begin{cases} \|\boldsymbol{x}_m - \boldsymbol{y}_n\| \geq R_P, \\ \|\boldsymbol{x}_m - \boldsymbol{x}_i\| \geq R_P, i \neq m \end{cases} \tag{2}$$

3. Rule 3: Ω should be as large as possible.

   To get an optimal coverage ratio, Voronoi partitioning is chosen to guarantee each ordinary nodes's working area. An online directionalCsearch algorithm is present in next section.

4. Rule 4: the number of each sub-network is similar.

   In order to play a more constructive role, each center holds similar quantity of ordinary nodes.

3. COVERAGE & PATH

3.1. CVT diagram

Review Voronoi diagram, which is a geometric model and optimization algorithm, it has broad applications in.... For a convex closed region W and N nodes, the region is partitioned to N subsets V_n,

$$V_m = \{\boldsymbol{x} \in \Omega | \|\boldsymbol{x} - \boldsymbol{x}_m\| \leq \|\boldsymbol{x} - \boldsymbol{x}_i\|, \forall i \in I\}, m \in I \tag{3}$$

With range limit, the Voronoi cell V_m is to r-limit Voronoi cell $\bar{V}_m$:

$$\bar{V}_m = \{\boldsymbol{x} \in \Omega | \boldsymbol{x} \in V_m \bigcap C_D, \} \tag{4}$$

whereC_D is the sensing range and is a circle with radius r. The node m is responsible for $\bar{V}_m$. Hence, the region under surveillance is the union of $\bar{V}_m$.

In our paper, the AUVs should move in a path to try and cover ideally the whole space W, considering their limited communication capabilities. Thus, the Voronoi cell and r-limit Voronoi cell are taken into account as the AUVs detection regions. For the later, the limit range is AUV's sonar detection range R_D, i.e, $r = R_D$. The region centers are the ideal position of AUVs. Hence, each nodes moves towards a geometric center of its own Voronoi region, and the navigation direction is ϕ. Further more, the next position must lay in $\bigcup_{n=1}^{N} C_n$. Otherwise, the node would decrease the moving distance for this step.

3.2. direction control

$\boldsymbol{x}_m(t)$ is the current coordinates of NO. m AUV, and $\boldsymbol{x}_m(t+1)$ is the true next coordinates. The navigation direction is chosen as the control input.

$$\boldsymbol{x}_m(t+1) = \boldsymbol{x}_m(t) + \boldsymbol{u}_m(t) \quad (5)$$

$\boldsymbol{u}_m(t)$ is the motion variation and decided by the motion destination, AUV speed, and control strategy. $\bar{x}_m(t)$ is the ideal next coordinates and should be the center of its own Voronoi polygon. The control input is decided as:

$$\boldsymbol{u}_m(t) = \begin{pmatrix} k_m v \cos \phi_m(t) \\ k_m v \sin \phi_m(t) \end{pmatrix} \quad (6)$$

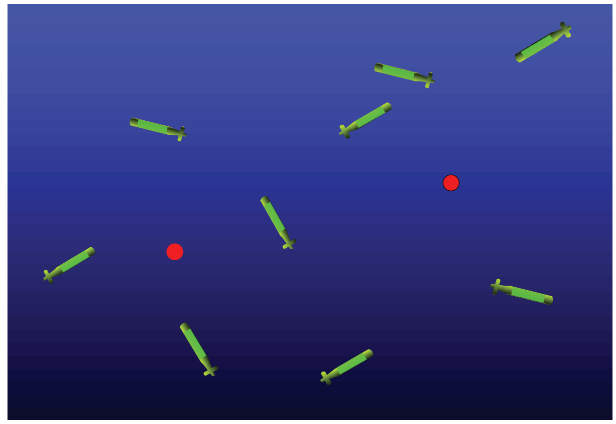
k_m is the control factor, and v is the maximum moved distance of the AUVs at one step (can be seemed as speed). $\phi_m(t)$ is the yaw from the current coordinates to the ideal next coordinates. Usually, k_m is set a bit bigger than 1. The AUVs' position must be checked for every step. If the estimated next coordinates cannot satisfy Eq.1 and 2, k_m would be set smaller.

3.3. grouping

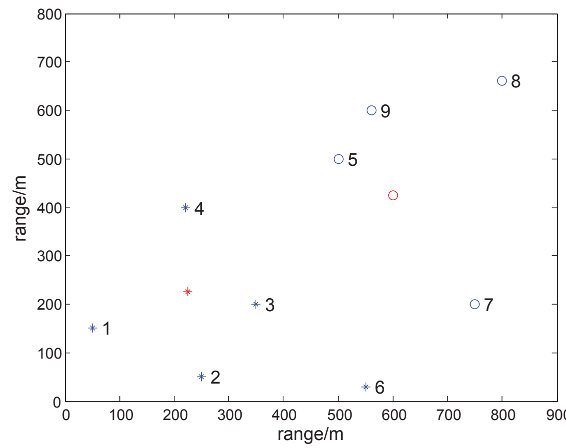
In the procedure, the AUVs are divided to different groups dynamically. In our paper, we group the AUVs according to the Euclidean distance. When some mobile node moves away from the prevenient center, the sub-network should be reconstructed, and the node would join in other nearer sub-network. For example, in Fig.1, the node 6 belongs to team 1, and is moving towards center 2. When the node is out of control from sonobuoy 1, for instance, the distance to center 1 is longer than to center 2, it would be divorced from team 1 and join in team 2.

4. SIMULATION

In this section, simulation will be carried to demonstrate our approach. Consider a region W to be surveyed as a 600m*500m square. The underwater network is composed of 8 AUVs and 2 sonobuoys, and should be grouped two teams. The sonobuoys' coordinates are $(150, 125)$ and $(360, 300)$, to cover the surveillance area as uniformly as possible. The AUVs are randomly deployed in the region while satisfying the communication constrains, and the initial directions of AUVs are all set as zeros. The maximum speed of AUVs is 3m/s.



(a) The red AUVs: center node; the green AUVs: common nodes



(b) Grouping the AUVs into two teams with symbols '*' and 'o'

Fig. 1. AUV network with two teams.

- $R_D^m = 110m$;
- $R_C^m = 280m$;
- $R_P = 10m$
- $k = 1.01$;

We suppose the AUVs are homogeneous and have same sonar detection range, and same communication range. During the network evolution, the eight AUVs are departed to two teams, of which the centers are sonobuoys. The hierarchy network's construction is shown in Fig.2 and 3, including the grouping results, the paths, and last positions. The subsets with different colors denotes the different AUVs' survey area, which are polygons in Fig.2 and $\bar{V}_m$ in Fig.3. Circles denotes sonobuoy and '+' denotes AUV. The grouping would vary when the AUVs' moving, and the two teams are distinguished by red and blue.

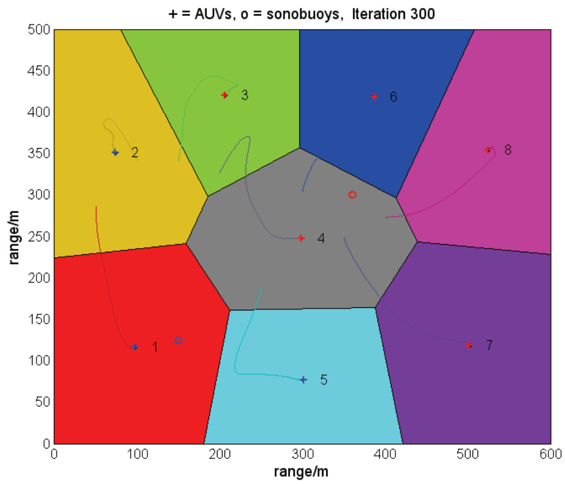


Fig. 2. segment by Voronoi

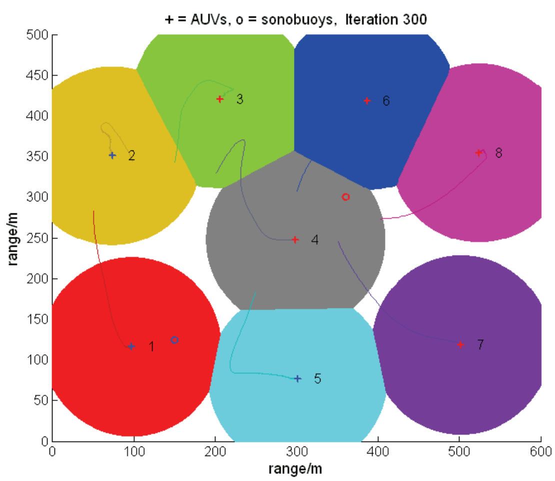


Fig. 3. segment by r-limit Voronoi

5. CONCLUSION

In this paper, a hierarchy underwater network consisted of AUVs and sonobuoys is presented. With consideration of communication range and detection range, the monitored area of each AUV is decided by Voronoi and r-limit Voronoi algorithms. While the AUVs' moving and some other special conditions such as node failure, the network should be reconstructed.

6. REFERENCES

[1] Andrea Caiti and Andrea Munaf, "Cooperative distributed behaviours of an auv network for asset protection with communication constraints," *Journal*, vol. 62, pp. 291–294, January 2011.

[2] Andrea Caiti, Vincenzo Calabr, Gianluca Dini, Angelica Lo Duca, and Andrea Munaf, "Auvs as mobile nodes in acoustic communication networks: field experience at the uan10 experiment," *Journal*, vol. 62, pp. 291–294, January 2011.

[3] Seokhoon Yoon and Chunming Qiao, "Auvs as mobile nodes in acoustic communication networks: field experience at the uan10 experiment," *IEEE Transactions on Parallel and Distributed Systems*, vol. 22, pp. 364–379, March 2011.

[4] J. Cort'es F. Bullo and S. Mart'nez, *Distributed Control of Robotic Networks*, Princeton University Press, 2009.

[5] John Stergiopoulos and Anthony Tzes, "Voronoi based coverage optimization for mobile networks with limited sensing range ł a directional search approach," in *Proc. of American Control Conference*, 2009, pp. 2642–2647.

[6] Chiraz Houaidia, Hanen Idoudi, and Leila Azouz Saidane, "Improving connectivity and coverage of wireless sensor networks using mobile robots," in *Proc. of IEEE Symposium on Computers and Informatics*, 2011, pp. 454 – 459.

[7] M. Herrb F. Ingrand F. Robert R. Alami, S. Fleury, "Multi-robot cooperation in the martha project," *IEEE Robotics and Automation Magazine*, vol. 5, pp. 36–47, 1998.