Research on the Method of Capturing Task Allocation Based on Energy Balance

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Abstract. With the constant research on the anti-capture strategy of Autonomous Underwater Vehicles (AUVs), it is more and more difficult for the AUVs to hunt motion. To this end, a multi-layer annular ambush capture model to improve the success rate of arrest. Based on the multi-layer annular ambush capture model, task-based mission assignment based on different characteristics of heterogeneous AUVs carrying energy is carried out. This distribution method enables heterogeneous AUVs to make full use of their own features better completion of the task. At the same time, considering the problem of uneven energy consumption in the system over time, an energy balance method is proposed to balance the energy consumption of the system. The method not only prolongs the life of the entire system and realizes the system running process dynamic task assignment. Experiments show that the method effectively improves the success rate of arrest and system life.

1. Introduction
In recent years, with the continuous development of robots, more and more are applied to different fields. With the increasing complexity of robot tasks, multi-robot system is becoming an important research topic of robot development, such as multi-robot localization, coverage, target tracking, capturing and so on[1-8]. Multi-robot rounding is a special implementation model of multiple robots coordinated pursuit and is one of the hot topics in the field of artificial intelligence.

Many scholars have carried out relevant research on the arrest problem. Xiongjun Feng et al.[9] put forward a virtual force-based approach to the problem of group robot encircling, and realized the multi-layer multi-target capture and dynamic target of the static target under the condition of non-convex obstacle Lay around the trap. L. Blazovics et al.[10] proposed a rule-based algorithm for single-target single-layer envelopment of group robots. These documents are confined to specifically shaped obstacles and do not take into account the specific task assignment of robots, and do not make the best use of heterogeneous robots to engage in orienteering. Currently, multi-robot task allocation methods mainly include the following: Behavior-based allocation methods such as ALLCANCE[11] and BLE[12], although these methods are real-time, fault tolerance and robustness, The optimal solution based on market mechanism is the mainstream task assignment method, such as First-price auctions[13] and Dynamic role assignment[14]. This method is particularly suitable for distributed robots because of its good scalability. In theory, it can guarantee the optimal allocation of tasks. However, the communication overhead in the process of task assignment is large. Once the communication is interrupted, the performance will be decreased[15]. Therefore, it is more suitable for small and medium-scale task assignment. Aiming at the roundabout motions of AUVs robots, a multi-layer annular
ambush arresting model is proposed. Based on the multi-layer annular ambush arresting model, the task allocation methods Task Allocation Method for Energy Balance (TAEB) and Task Allocation Method for Improved Energy Balance (TAIEB) are proposed.

2. Another section of your paper

2.1. multi-layer annular ambush capture model

The traditional capturing is encircled by a polygon or encirclement that is made up of AUV. Wang Haojie [16] and others put forward a single layer ring, which is the center of the target T, the circle of R is called the circle of capture, and the R is the radius of the capture. When the T is in the middle of the encircling, the capture is completed, and all the rounded AUV should be evenly distributed in the ring. Although the hunting model proposed by Wang et al. Has improved the success rate of catching up to a certain extent, with the deepening of AUV anti-hunting strategy, AUV's anti-hunting capability has been strengthened. The single circle is often difficult to achieve effective hunting targets. Therefore, a new multi-layer cyclic ambushed model is presented in this paper, as shown in Fig 2.1.

![Fig.2.1 multi-layer annular ambush rounded up mode](image)

Here, the hierarchical foundation of the system is based on the distance \( L \) that each AUV sonar can explore. (the default AUV sonar exploration distance is equal to the AUV transmission communication distance). In this system, the actual distance of each AUV is \( r = \varepsilon L \) (\( 0 < \varepsilon < 1 \), here we take \( \varepsilon = 0.8 \)). The relationship between the width of the circle \( R \) of the \( i \) layer and the AUV radius of the I AUV sonar is \( R < 2r \) (taking into account the scanned blank area that may exist in the circular area, where the R-value is less than 2r), making the detection area overlapping the \( i \) layer and the \( i-1 \) layer as small as possible. At the same time, the range of search for each robot is further divided. Each layer is divided into AUVs detection area according to \( L \). After that, every layer of EPI decreases \( a (a \in (0, \varepsilon)) \) in sequence according to the number of layers.

(1) the quality and shape information of the capture of AUVs and target AUV is ignored, and the speed is constant.
(2) ignore the time that the moving AUV adjusts the motion angle.
(3) a two-dimensional coordinate system is set up in this paper, which takes one of the obstacles in the area as the center of the coordinate system.
This multi-layer ring ambush rounded model can better target surveillance AUV hide, and improve the limitations of the traditional ring of encirclement, thereby increasing the success rate and efficiency of round-up operations.

2.2. AUV system

Initially, the motion direction and velocity of the target AUV are unknown. The speed of the AUVs is not necessarily greater than the speed of the target AUV, especially given the worst case, that is, the speed of the AUVs is less than the target AUV speed, if still using the conventional strategy, the probability of successful roundabout is almost zero. In this case, the selection of ambush by AUVs is a better strategy, and the use of multi-robot system as a whole can ensure a higher success rate, and the ambush strategy can reduce the energy consumption of the roundabout. This method is more common when animals are predatory in nature.

This paper on the AUV system to do the following division:

Ambush AUVs: The ambush AUV is hidden behind the obstacle and the AUVs is distributed in a ring-like manner for the AUV with less energy and the ambush AUV can monitor the target AUV without obstructions.

Search / rounded up AUVs: In addition to ambush AUVs, the rest of the remaining AUV team became search for AUVs team and dynamic search of target AUV. When searching for the target AUVs, the discoverer and the nearest AUVs become the hunt AUV.

Interception AUV: hunt AUV will target AUV escape speed and direction to inform the interception group, intercept AUV forecast t time after the target AUV position, it's diagonal blocking.

When the target is besieged, the target AUV is not less than the center distance of the two round-trip AUVs, regardless of the center distance of the two adjacent round-trip AUV connections. The expression is:

$$D_i \leq d$$

$$\sum \theta_i - \frac{2\pi}{n} \leq \frac{\pi}{4}$$

Where $D_i$ is the distance between the rounds of the AUV and the target, $d$ is the size of the enclosing radius, $n$ is the number of rounds to arrest AUV, and $\theta_i$ is the angle between the two enclosing AUVs and the target AUV, Where $i = 1, 2, 3 ... n$.

2.3. AUV energy model

AUVs communication methods mainly use acoustic communication, but in the long-distance underwater communication energy consumption is very large, underwater communication by many factors, such as transmission frequency, transmission speed, path loss and transmission loss. Therefore, all of these factors must be considered for the energy consumption model designed for acoustic communication.

$D_i(x, d)$ Represents the energy consumed by the robot $i$ at the distance $d$ to transmit the $x$-bit data.

$$D_i(x, d) = xP\nu^d d^k$$

Where $P$ represents the energy required to transmit a bit, where $k$ represents the coefficient and $\nu$ is the absorption coefficient in dB / km. The value range of the coefficient $k$ is [1, 3], and the value is 1.5. The absorption coefficient is based on the signal frequency measured in kHz, and the absorption coefficient can be calculated as $^{[17]}$.

$$\nu = 10^a(f)/10$$

Where

$$a(f) = 0.003 + \frac{0.11f^2}{1 + f^2} + 2.75 \cdot 10^{-4} f^2 \cdot \frac{44f^2}{4100}$$

Where $f$ represents the signal transmission frequency.
3. AUVs energy balance task assignment method

In this paper, the task allocation strategy based on round-robin is based on the intelligent nature of the target AUVs, which can take a series of anti-snatching operations when it is detected that it has been besieged. The default communication between AUVs within the system is good.

3.1. AUV anti-encirclement strategy

With the AUVs anti-surround research, AUVs has more and more intelligent anti-round-up ability, that is, the target AUV adopts the optimal escape strategy according to different situations. The first is the behavior of the escape round-up group, and the second is the behavior of the break-out encirclement.

When the chaser group is not surrounded by the target robot, the target robot adopts the "comprehensive consideration" escape strategy, that is, the direction of the superposition of the motion state vector of all the hunt robots in the sensing range, as the direction of their escape:

\[
V_p = \sum_{j=1}^{\text{PR}} V_j
\]

In Fig.3-1a, \(d_{\text{PR}}\) is the distance from the target AUV to the midpoint of the two hunt AUVs. The target distance of the design target AUV is \(d_{\text{PS}}\). When \(d_{\text{PR}} < d_{\text{PS}}\), the target AUV will escape at maximum speed. The target AUV escape strategy is to pursue the vector synthesis direction of the AUV speed and perform the maximum speed escape in this direction.

As shown in Fig.3-1b, the target robot is surrounded by the target robot, but when the round robin task has not yet been completed, the target robot uses the "maximum angle" breakout strategy, that is, the selection of two adjacent hunt robots with the target AUV as the vertex angle The largest, for the two hunt the robot location of the middle of the line to break through.

![Fig.3.1 Schematic diagram of target AUV escape direction](image)

Where \(x_{12} \neq y_{12}\), are the midpoints of the two corners with the largest angle between the target AUV and the target AUV. \((x_p, y_p)\) is the current coordinate of the target AUV. The speed of the escape is the maximum speed of the target AUV. When \(d_{\text{PR}} < d_{\text{PS}}\), the breakout is successful. Otherwise it will be captured.

\[
\gamma = \arctan\left(\frac{y_{12} - y_p}{x_{12} - x_p}\right)
\]

It can be seen that, for different situations, the target AUV can choose the appropriate escape strategy to avoid hunt, if you want to quickly round the target AUV, the corresponding task allocation strategy is a prerequisite, then the rounded AUVs designed a good task allocation Strategy is essential.

3.2. TAM

The percussion AUVsS consists of \(n\) heterogeneous AUVs, that is, the energy \(E_j\) \((j=1,2,\ldots,n)\) carried by the individual individuals in \(n\) AUVs, and the energy carried by AUVs directly affects its
running time. Task Allocation Method (TAM) divides the energy levels carried by each AUVs at the initial stage by the energy level $EL$. 

$$EL_j = \frac{E_i}{n}$$ (7)

According to the $EL$ of the AUVs from small to large number, to get the order of the capturing AUVs $\{A_1, A_2, A_3, \cdots, A_n\}$. 

TAM gives priority to the allocation of ambush missions to AUVs. According to the actual situation, the ambush of AUV needs to meet the following conditions: AUV with less energy and not suitable for long-term movement; AUV with obstacle nearby; ambush AUVs queue has a ring-Arrangement.

According to the needs of the actual situation in the process of arresting, the $m$ AUVs with less energy after the selection of $n$ trapped AUVs constitute the alternative group of ambush AUVs $\{A_1, A_2, A_3, \cdots, A_n\}$. The selected ambush AUVs candidate group uses their sonar to detect the presence of an obstacle in their vicinity at the current position, and if there is, moves to the nearest obstacle to avoid it; if not, the AUV is moved from the ambush candidate group Delete, select the smallest surviving AUV in non-ambush AUVs Repeat the above process. The excluded AUVs join the search queue as a searcher to perform a roaming search on the target AUV in the target area.

Observe the evasion position in the ambush AUVs candidate group to investigate whether the ambush AUVs cohort is in a multi-layer annular arrangement as discussed below by the requirements of the multi-layer annular ambush array:

If the ambush AUVs does not satisfy the hierarchical ring arrangement, consider the worst case where all the ambush AUVs are on the ground floor, then each ambush AUV in the ambush AUVs detects the obstacle to the inner layer to see if there is a inner layer to avoid obstacles. If there is an ambush AUV detects an inner obstacle, the ambush AUVs that detect the inner obstacle are sorted according to the size of the energy and are selected to carry the layer with the more energetic AUV. If there is no ambush AUV finds an inner obstacle, Sent a weak non-ambush AUV and the corresponding number of energy ambush AUVs to search the inner obstacles, if the no ambush AUV first arrived at the inner obstacles then the inner search barrier is energetic ambush The AUV performs the role replacement, repeating the above sequence until the ambush AUVs layering is successful.

Followed by AUVs dynamic allocation search task allocation. In addition to ambush AUVs, the remaining AUV team to search for AUVs team and dynamic search of the target AUV ambush AUVs although evasion behind the obstacle, in the barrier-free surface can sonar, static search of the target AUV. If you find the target AUV is divided into the following two cases:

1) The search AUV finds the target AUV, then immediately communicates the direction and speed of the target AUV's general motion to the neighboring AUVs, and the discoverer and the search AUV which are closer in the distance construct a temporary chase queue. Trying to drive the target AUV into the encircled ambush AUV.

2) If an ambush AUV finds a target, then the Hurricane AUV communicates with the other nearby AUVs, regardless of the amount of energy the ambush AUV carries, and to communicate the direction and speed of the target AUV's general motion to other AUVs Temporary chase queue, hunt for the target AUV, and trying to drive the target AUV into the ambush with ambush AUV.

As the system continues to operate, individual AUVs energy consumption will be too fast, and its remaining energy can no longer effectively bear its current tasks. This situation can not be ignored and has an extremely important impact on the success of the round-up campaign.

3.3. EBS

When the system is running for some time, some of the existing energy of the AUVs may not be able to continue to perform its tasks effectively, and it is difficult or almost impossible to replace the battery in a harsh water environment. To this end we propose Energy Balance Strategy (EBS), EBS using the rotation mechanism to reduce the energy of the AUVs rotation to the lower energy consumption of the location, balance the system energy consumption.
1) The AUVs in the system detects the target AUV, that is, it hunts the target AUV according to the hunt strategy. After completing a hunt task, the energy consumption of the AUVs involved in the hunt is significantly larger than that of the AUVs not involved in the hunt. AUVs involved in the capture time is \( T_h \), the energy consumption of AUVs movement per unit time is \( R_0 \).

AUVS\(_h\) kinetic energy consumption is:

\[
\Delta E = T_h \cdot R_0
\]

(8)

AUVS\(_h\) communication consumption is:

\[
\Delta E = xPv^L \cdot (Le)^{\beta}
\]

(9)

Where \( \varepsilon \) represents the value of the layer of the AUVS\(_h\) (\( h = 1, 2, ..., n \))

Complete a round robin total energy consumption is:

\[
\Delta E = xPv^L \cdot (Le)^{\beta} + T_h \cdot R_0
\]

(10)

2) The greater the search range of the AUVs detection in the system, the greater the energy consumption of the AUV after the search for a period of time. AUVs unit time unit distance from the sonar detection once required energy recorded as \( S \), then after the time interval \( \Delta t \) after the i-level scan in the consumption of energy:

\[
\Delta E = \Delta t \cdot S \cdot \varepsilon_i
\]

(11)

AUVs After completion of a job rounding up, rounding AUVs participate in their energy levels are sequentially checked from the beginning AUVS\(_0\) i-th layer, their energy level when AUVS\(_0\) found to sequentially drop the inner inquiry, found AUVS\(_p\) energy levels when \( k \) is greater than the layer itself When AUVS\(_0\) stops the query immediately to AUVS\(_p\) where the area is replaced by AUVS\(_p\). At the same time, the AUVs is moved from the beginning of the \( k + 1 \) layer and the AUVs is moved from the AUVs in the area where the AUVS\(_0\) is located. If the upper layer participates in the round-up movement, the AUVs with the highest level is selected, and the position of the AUVs is continuously repeated. That is AUVS\(_p\) moved to \( k + 1 \) layer, \( k + 1 \) layer selected AUVs moved to \( k + 2 \) layer, until the completion of the i-level replacement. When all the round-robin AUVs completes a query and replaces, it completes a rotation, and then continues down from the i-1 layer. Repeat this process until all AUVs participating in the round-robin are replaced.

If the system has not found the target AUVs, the energy consumption of all AUVs in each layer can be approximated as the same and starting from the outermost layer, since the trailing motion is not carried out. Then after the time interval \( \Delta t \), the energy level query is started from the outermost layer in turn. If the energy level of the i-th layer is lower than that of the i-th layer, the i-th layer is switched to the i-th layer, and since the number of the two-layer AUVs is different, the i-th layer is not exchanged. After a time interval \( \Delta t \), it is preferentially exchanged. After the exchange of the first i layer to the first i-2 layer query, if the level is still low to continue to exchange, or from the first i-2 layer to the next query. Followed by the exchange of inquiries, until the completion of the entire system AUVs replacement, if the exchange in the way to find the target AUV immediately tentative exchange, turn around.

3.4. Improved energy balance strategy IEBS

Due to the uncertainty of the energy budget of the task of arresting, after the completion of a mission, the residual energy of the robots participating in the round-off may no longer have the value of rotation. Therefore, this paper proposes an improved energy balance strategy IEBS. The IEBS introduces the weight \( \beta \), and the remaining energy of the AUV that needs to be rotated after the round-up movement is \( E_{res} \), and it is judged whether \( E_{res} > \beta \) it is satisfied when performing the rotation. Here \( \beta = 2F \), the specific calculation process of F is given below.
Suppose the \( \text{AUVs}_{\text{rot}} \) current need to rotate in the i-layer need to exchange to the k-layer, the remaining energy is \( \Delta E \), from (8) calculated by the i-layer to k-layer energy consumption, ignoring the query energy consumed.

\[
\Delta E = \varepsilon_i L + (i - k)(i - k - 1) \cdot aR_i / 2v_0 \tag{12}
\]

\( v_0 \) is the AUV average speed.

Calculate the survival time before and after the \( \text{AUVs}_{\text{rot}} \) exchange of positions, no longer consider the situation involved in the capture.

\[
T_1 = \frac{E_{\text{res}}}{E_i} \tag{13}
\]

\[
T_2 = \frac{E_{\text{res}} - \Delta E}{E_2} \tag{14}
\]

Where \( T_1 \) is the life time without exchange, \( T_2 \) is the life time after exchange, \( E_1, E_2 \) are the energy consumed for search in the unit time of layer i and layer k, respectively, and can be obtained from (11).

\[
E_1 = L\varepsilon_i R_i \tag{15}
\]

\[
E_2 = L\varepsilon_k R_k \tag{16}
\]

The (14) - (13)

\[
T_2 - T_1 = \frac{E_{\text{res}} - \Delta E}{E_2} - \frac{E_{\text{res}}}{E_1} \tag{17}
\]

(17) \( > 0 \), AUV rotation has practical significance. That is needed \( E_1(E_{\text{res}} - \Delta E) - E_{\text{res}}E_2 > 0 \).

Substitute (15) (16) into.

Left = \( L\varepsilon_i R_i (E_{\text{res}} - \Delta E) - L\varepsilon_k R_k E_{\text{res}} \).

Simplify = (\( i - k \))\( aE_{\text{res}} - \varepsilon_i \Delta E \).

Substituting (12) into the simplified.

\[
E_{\text{res}} > \frac{2V_0 L\varepsilon_i^2 + aL\varepsilon_i(i - k)(i - k - 1)}{2aV_0(i - k)} \tag{18}
\]

The original is proof (18) \( > 0 \), note

\[
F = \frac{2V_0 L\varepsilon_i^2 + aL\varepsilon_i(i - k)(i - k - 1)}{2aV_0(i - k)} \tag{19}
\]

When the AUVs is running out of energy, the AUVs always runs out of energy and stops working. When an AUVs is exhausted, it immediately informs the co-located AUVs to move closer to it and expands the remaining AUVs detection range until it completely covers the depleted AUVs area. When AUVs continues to be exhausted after the AUVs exploration search of the same layer is extended to \( L \), the AUVs of this layer informs the upper AUVs to start to shrink the system range, that is, the arresting system is reduced from \( i \) to \( i - 1 \). If an exhausted AUVs appears in the outermost layer, the outermost layer is abandoned directly. The outermost AUVs moves all the way inwards and redistributes the search area.

After AUVs carries out its rotation, its tasks are also changed accordingly. For example, after the initial ambush robot runs for a certain period of time in the system, the energy of other robots is finally lower than the ambush robots because the energy of other robots is lower than that of the other robots. The ambush robot will be rotated, and the lower-powered robot will be the ambush robot.
4. Experimental

The task allocation strategy based on rounding and the energy balance strategy proposed in this paper are not specific rounding algorithms. Therefore, we combine the Q-learning algorithm and the strategy of this paper to validate the feasibility of the strategy based on rounding task allocation and energy balance strategy. Compared with the traditional one-layer tracking algorithm, the simulation environment is set to a square area of 10m × 10m, and the data packets communicated between the robots are 200bit.

AUVs a battery can usually carry about 30WJ energy, in order to simplify the calculation, this article will choose 15 AUV. Each AUV carries the energy as follows:

| AUVs | 1   | 2   | 3   | 4   | 5   |
|------|-----|-----|-----|-----|-----|
| energy (J) | 480 | 320 | 280 | 500 | 360 |

| AUVs | 6   | 7   | 8   | 9   | 10  |
|------|-----|-----|-----|-----|-----|
| energy (J) | 240 | 350 | 270 | 460 | 500 |

| AUVs | 11  | 12  | 13  | 14  | 15  |
|------|-----|-----|-----|-----|-----|
| energy (J) | 380 | 290 | 450 | 330 | 410 |

Other data settings are as follows:

| parameter | value |
|-----------|-------|
| P         | 0.3 × 10^7 bit/J |
| f         | 20kHz |
| d_{PS}    | 2m    |
| Δt^4      | 30s   |
| V_a       | 1m/s  |
| a         | 0.1   |
| R_0       | 2J/s  |
| L         | 10m   |
| L         | 10m   |

4.1. EBS and IEBS simulation experiments

In order to verify the energy balance strategy proposed in this paper, this experiment uses the target AUVs to be randomly found every 2 minutes in the system, that is, to conduct an inhumane movement. When the AUVs energy exhausted due to a certain involved in the capture led to the failure of the catching test, the result of the experiment is shown in Figure 4.1.
From the experimental results, it can be seen that the system life of the EBS method finally balances to 880s, and the traditional Q learning algorithm equilibrates to 680s, the difference between the two is 200s because EBS balances the energy consumption of AUVs and EBS always ensures that the highest energy AUVs is in energy At the fastest, AUVs with lower energy is maintained at lower energy consumption, ensuring that an AUVs does not directly deplete energy due to excessive energy consumption due to frequent work, thus improving the life of each AUVs Thus enhancing the life of the entire system. IEBS eventually converges to about 920s, which is due to the small range of the model of the roundabout and the low energy consumption of the EBS rotation robots during the rotation. Therefore, the gap between the two is small, but it can be seen that IEBS is superior to EBS.

4.2. TAEB and TAIEB simulation experiments

Using the TAEB and TAIEB methods in the Q learning rounding algorithm, we performed 30 experiments, each performing a total of 15 injections every 1 minute for a total of 450 experiments. Catches the target randomly, the target experimental results shown in Figure 4.2

![Success rate vs Number of experiments](image)

**Fig.4.2 TAEB&TAIEB method experiment**

From the experimental results, it is obvious that TAEB method has a successful success rate around 76%, TAIEB method around 87%, traditional Q learning algorithm 55%, TAEB method and TAIEB method. This is because TAEB and TAIEB have assigned AUVs static and dynamic tasks based on their own energy characteristics. TAM system in the beginning of the establishment of AUVs static mission, the allocation of high energy AUVs chase interception, the pursuit of interception mission is the task of the entire capture task most need to consume energy, only enough energy to ensure that as long as possible to pursue the interception in order to ensure The success of the roundabout. At the same time, EBS improved the success rate of the entire round-up task by shifting the position of the AUVs with excessive energy consumption, balancing the energy consumption of the entire system and ensuring the energy-rich AUVs in the peripheral position to ensure the successful completion of the pursuit-interception task. In addition, a set of experiments over 900s TAEB and traditional Q learning algorithm to effectively trap system life time, so the success rate of the capture less. However, compared with TAEB and traditional Q learning algorithm, TAIEB has an effective system life of 920 seconds, so the success rate of TAIEB compared with TAEB and traditional Q learning algorithm is significantly improved.

5. Conclusion

Based on the single ring up model is proposed on the multi ring ambushing model based on multi ring ambushing model is proposed on the hunting task allocation strategy and energy balance strategy based on EBS and TAM. TAM static allocation of round-up tasks, so that high energy MAUV is in the outer position to ensure the successful completion of pursuit interception task. The EBS energy balance strategy in the running process of the system to balance the energy consumption and the whole system has been made outside the MAUV energy is the largest, further enhance the hunting task
success rate, simulation results also proved this point. The strategy proposed in this paper can be used not only for Q learning round-up algorithm, but also for other round-up algorithms. In the future, we will consider the strategy presented in this paper for more complex situations.

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