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The Command Decision Method of Multiple UUV Cooperative Task Assignment Based on Contract Net Protocol

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Abstract With the help of multiple UCAV cooperative task control model, the mathematical model of multiple UUV cooperative task control is made. Variables related to decision are broken into goals, guidelines and programs levels by Analytical Hierarchy Process (AHP), on this basis; the command decision of multiple UUV task assignment is achieved. The correctness of task allocation algorithm is verified by case analysis. Time calculation formulas for a task assignment are given. The changes of overall effectiveness in the process of task allocation are analyzed, the time changes of each sub task allocation time in one task assignment are analyzed, the time changes of the number of tasks and platforms respectively fixed in task allocation are also discussed.

Keywords CNP; UUV; AHP; task allocation; command decision

1 Introduction

UUV (Unmanned Undersea vehicle)[1–3] equipped with sensors and task modules of different missions, can execute search, alert, target identification, monitoring, tracking, electronic interference, mine detection, mine sweeping, network communications, firepower and other combat missions. As a unique underwater combat force, it is becoming a new kind of combat platforms and getting more and more Naval' attention.

Multiple UUV task allocation is that the suitable UUVs are picked out from an existing database in order to complete a combat mission, and optimal allocation of resources must be met.

At present, the algorithm for realizing intelligent control to MAS can be summarized by the following, CNP model, blackboard model, Markov decision process model, Node planning methods, set covering theory, market agreement methods, and so on[4], in which CNP model has achieved good results in dynamic task allocation. CNP model is proposed on classical coordination strategy of task and resource allocation by Smith R.G. and Davis R. The basic

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ideal is that task allocation is achieved by using market mechanism of bidding-submitting-winning between nodes, which the contractual relationship can be completed at a low price and high quality.

CNP model has been widely used in robot[5], formation coordinated operations[6, 7], satellite[8], and multiple UCAV operations[9] and other areas. Reference [10] indicates the goal of task allocation is minimum cost and maximum effectiveness, the maximum number of tasks is restricted to reduce the computational complexity. Reference [11] proposes time Petri net that includes price and time cost can stimulate CNP negotiation process, improve operating mechanism of CNP. References [12, 13] introduce trust and punishment mechanism based on traditional contract net protocol to reduce the number of communication by limiting the scope of sending tender and controlling the number of evaluated tender. Reference [11] proposes an adaptive strategy and the number of communication is decreased, which various mental parameters are introduced to limit the scope of tender, and the buffer is set to limit the number of bidders receiving tenders.

This paper defines a number of related concepts of multiple UUV collaborative task control, analyzes the relationship between the tasks of the various constraints and it comes down to timing constraints and facilitate constraints two typical type based on the above basis and the model of multiple UUV cooperative task control[14, 15]. Then the model of multiple UUV task, cooperative target and task control are established. Various constraints relations relevant to make decision are broken down into goals, guidelines, programs and other levels by the methods of AHP, on this basis, the decision method of multiple UUV task allocation. The correctness of task allocation algorithm in this paper is demonstrated through case studies. Time formula of a task assignment is given. The changes of overall effectiveness are analyzed during the task assignment, the timing changes of each sub task are analyzed during a task assignment process, the timing changes of task allocation are also analyzed during the number of respectively fixed tasks and platforms.

2 Mathematical Modeling to Multiple UUV Cooperative Task Assignment

Related elements of multiple UUV cooperative task control problem can be described as a six sets $\{E, V, T, M, F, C\}$[14], E stands for battlefield environment, $V = \{V_1, V_2, \cdots, V_{N_V}\}$ stands for the set of UUV, $M = \{M_1, M_2, \cdots, M_{N_M}\}$ stands for the set of danger, $F = \{F_1, F_2, \cdots, F_{N_F}\}$ stands for the set of forbidding area. C stands for constraints, including UUV constraints of performance, task, tactics, battlefield environment, and so on. Assuming one UUV can run multiple tasks during a combat, but the task number of one UUV is corresponding restricted each time because of the limit of weapon and fuel resource. Tasks are divided into several types, such as target recognition, target attack, damage assessment, and so on, UUVs are divided into several types. It is quite different for different type UUV to perform a same type task. UUVs should avoid enemy threats and forbidding region in the battlefield environment.

1) Multiple UUV task model

Assuming that a number of goals are found through preliminary investigation in combat zone. According to the results of the investigation, the characteristics and importance of the targets, some targets can be attacked directly, some may be confirmed before an attack, and some important goals may need to be conducted damage assessment after an attack. So a target may include a task but also contain a series of tasks, such as an important goal needs to be performed three tasks, validations, attack and damage assessment. According to the above principles, we can get a series of tasks $T = \{T_1, T_2, \cdots, T_{N_T}\}$, in which each sub task can be directly performed by a single UUV. Task point can model to task. Task point may include target identification, target location, timing window, priority and other information, but also contain the types of tasks. So a target can be a task point, but also could contain multiple tasks. Notable features of multiple UUV cooperative mission control problem is numerous constraints, as shown in Figure 1. In addition to capacity constraints, tactical constraints, battlefield constraints, the task constraints are also included. As the complexity of combat mission, tasks in the set can be divided into two categories, one is independent task constraints and the other is cooperative task constraints which is that tasks exist functional constrains not only own constraints. Task own constraints mainly include time and quality constraints.

- constraint set
  - capacity constraints
    - dive depth
    - speed
    - voyage
    - detection performance
    - autonomous making-decision capacity
  - tactical constraints
  - battlefield constraints
  - tasks constraints
    - independent task constraints (task itself constraints)
      - time constraints
      - quality constraints
    - cooperative task constraints
      - timing constraints (uncertainty constraints)
        - precedence constraints
        - time constraints
      - functional constraints (non-uncertainty constraints)
        - enable constraints (mandatory constraints)
        - promote constraints (non-mandatory constraints)

Figure 1 The constraints of multiple UUV cooperative combat between tasks

Definition 1 (Time constraints) It means the tasks have a time constraints if the tasks must be finished in fixed timing window $[\mathrm{ETime}(T_i), \mathrm{LTime}(T_i)]$. The earliest start time for the task is $[\mathrm{ETime}(T_i), \mathrm{LTime}(T_i)]$, and the latest time is $\mathrm{LTime}(T_i)$, UUV can not finish the tasks if it arrives early or late.

Definition 2 (Quality constraints) If the tasks results must meet specific requirements, such as how much does the sensor' resolution has, what type missile should use to destroy the targets, it means the tasks have a quality constraint.

Tasks constraints can be divided into timing constraints and quality constraints, timing constraints mainly refer to time constraints between tasks, functional constraints contain enable constraints and promote constraints.

Definition 3 (Timing constraints) If the tasks T_i and T_j must be completed simultaneously or sequentially in the order, it means the tasks have a timing constraints, and it can be described by $\mathrm{Sequence}(T_i, T_j)$, tasks that have timing constraints with T_i can constitute a set $S^{\mathrm{Seq}}(T_j)$. A group tasks with timing constraints can be called timing group, tasks before T_i call predecessor task of T_i, tasks after T_i call successor task of T_i. If T_j immediately follows by T_i, T_i can be call immediate predecessor of T_j, T_j can be call immediate successor of T_i, all the T_i immediate predecessor can constitute a set $S^{\mathrm{Pre}}(T_j)$, all the T_i immediate successor can constitute a set $S^{\mathrm{Suc}}(T_i)$.

As shown in Figure 2, $T_1 - T_5$ can constitute a timing group, in terms of T_2, $S^{\mathrm{Seq}}(T_2) = \{T_1, T_3, T_4, T_5\}$, predecessor tasks are $\{T_1\}$, immediate predecessor is $\{T_1\}$, successor tasks are $\{T_3, T_4, T_5\}$, immediate successor is $\{T_3, T_4\}$. T_3 and T_4 are parallel relations, it has un-direct link between, but they are affected by common immediate predecessor task T_2, they have an impact on common immediate successor task T_5.

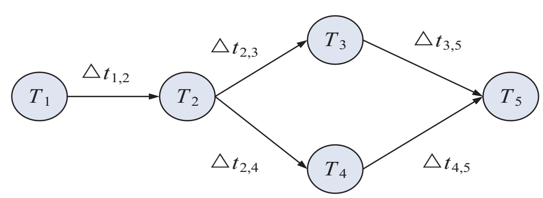


Figure 2 Schematic diagram of timing group

In the battlefield environment, as to any timing group, all the tasks must be finished in a short time. There is very short interval between predecessor and successor, such as attack must be launched immediately after target recognition. Then damage assessment must be performed after the end of attack. So a UUV can only undertake a task in timing group, a timing group needs a series of UUV with the completion in compact time.

Definition 4 (Enable constraints) Task T_j can not finish if task T_i is not completed, in other words, Task T_i depends on the implementation of task T_j, it means T_i has enable constraints to T_j, which can be described by $\mathrm{Enable}(T_i, T_j)$. $S^{\mathrm{Enable}}(T_j)$ is the set of tasks that have enable constraints to $S^{\mathrm{Enable}}(T_j)$.

Definition 5 (Promote constraints) If task T_i can help to finish T_j, in other words, it can decrease the time or costs of completion to T_j, or it can improve the quality of task T_j, but it has no affect to finish T_j if task T_i has not been finished, it means that T_i has promote constraints to T_j, which can be described by $Faciliate(T_i, T_j)$, $S^{Fac}(T_j)$ is the set of tasks that have promote constraints to T_j. Timing constraints between tasks is mandatory constraints, and it must be met. However, promote constraints are non-mandatory constraints, and it should be met as much as possible in the combat process.

2) Control objectives of multiple UUV cooperative tasks

Before control objectives of multiple UUV cooperative tasks are proposed, corresponding methods must be established to measure the effect of UUV. Learning from the concept of military operational effectiveness, this paper uses task effectiveness to comprehensively reflect the quality of UUV costs and gains.

Definition 6 (Task effectiveness) The task effectiveness $U_i(T_j)$ of UUV V_i is equal to $\text{Reward}_i(T_j)$ minus $\text{Cost}_i(T_j)$.

$$U_i(T_j) = \text{Reward}_i(T_j) - \text{Cost}_i(T_j).$$

Because $\text{Reward}_i(T_j)$ and $\text{Cost}_i(T_j)$ have different dimensions, first of all, normalization must be executed. Subtract can be executed until they have the same dimension[16].

The rewards of UUV depend on the value of tasks and the ability of UUV to perform task. The value of tasks generally is preset by commanding officers according to certain tactical principles; dynamic adjustment can be executed according to changes of battlefield situation and operational intentions. The ability for UUV to fulfill tasks depends on its own properties, weapons and sensors; it is usually described by corresponding probabilities based on past statistics. Assuming V_i execute a target recognition task T_j, $P_i^C(T_j)$ is the recognition probability of this type. $\text{Value}(T_j)$ is the value of tasks, so the reward can be described by the following,

$$\text{Reward}_i(T_j) = \text{Value}(T_j) \cdot P_i^C(T_j).$$

Assuming V_i execute a target attacking task T_k, $P_i^A(T_j)$ is the killing probability of this type. $\text{Value}(T_k)$ is the value of tasks, so the reward can be described by the following,

$$\text{Reward}_i(T_k) = \text{Value}(T_k) \cdot P_i^A(T_k).$$

Assuming V_i execute a target damage assessment task T_l, $P_i^V(T_l)$ is the damage probability of this type. $\text{Value}(T_l)$ is the value of tasks, so the reward can be described by the following,

$$\text{Reward}_i(T_l) = \text{Value}(T_l) \cdot P_i^V(T_l).$$

The tasks costs include distance costs LengthCost and risk costs RistCost. Distance costs are the time-consumption and fuel consumption for UUV arriving at the mission location. In order to short time and decrease the consumption, UUV tends to execute nearest tasks and straight routes with the consideration of distance costs. However, waiting time may need to be increased to achieve coordination with other UUVs, The fact that time for different UUV navigation and executing tasks is quite different should take into account, so time costs can be instead of distance costs. $\text{TimeCost}_i(T_j)$ is the time costs for V_i executing task T_j, $\text{TimeCost}_i(T_j) = t_i^{\text{flight}}(T_j) + t_i^{\text{wait}}(T_j) + t_i^{\text{execuite}}(T_j)$. There are risk costs because of the threat of enemy in battlefield environment, which means the risk that UUV is found or attacked by enemy in the sailing route. Risk costs make UUV avoiding the threat of enemy to ensure its safety. Time costs and risk costs are closely related to sailing route.

Assuming that $\mathrm{Reward}_i(T_j)$ is the reward for V_i executing task T_j, $\mathrm{TimeCost}_i(T_k)$ is time costs and $\mathrm{RiskCost}_i(T_k)$ is risk costs, so the effectiveness $U_i(T_j)$ can be described the following, $U_i(T_j) = \mathrm{Reward}_i(T_j) - \alpha_1 \cdot \mathrm{TimeCost}_i(T_j) - \alpha_2 \cdot \mathrm{RiskCost}_i(T_j)$. The different value of α_1, α_2 can reflect the importance of each objective function and the decision preference of different commanding officers.

After UUV collaborative effectiveness is obtained, the objectives of multiple UUV collaborative control can be described as the following.

Goal 1: Tasks are assigned to a number of UUV, in other words, $\cup_{i=1}^{N_V} S_i = T$, and we must make sure that one task is assigned to only one UUV. $\forall i, j \in \{1, 2, \cdots, N_V\}$, if $i \neq j$, $S_i \cap S_j = \emptyset$. If the number of tasks exceeds the maximum number that can be finished by UUV in the combat, the tasks that can improve the total effectiveness can be taken precedence.

Goal 2: The total effectiveness of tasks $\sum_{i=1}^{N_V} U_i(S_i)$ should be biggest, $U_i(S_i)$ is the effectiveness of V_i finishing S_i.

Goal 3: Time of tasks $\max_{i \in V} \mathrm{Time}_i(S_i)$ should be least, $\mathrm{Time}_i(S_i)$ is the time of V_i finishing S_i.

Goal 4: Task loads are should keep balance, in order words, $\sum_{i=1}^{N_V} \left|\mathrm{TLoad}_i(S_i) - \overline{\mathrm{TLoad}}\right|$ should be least, $\mathrm{TLoad}_i(S_i)$ is the loads of V_i, which is the ratio of current number of tasks and the number of UUV can sustain, $\overline{\mathrm{TLoad}}$ is the average loads.

3 Task Allocation Decisions Based on AHP

AHP (Analytic Hierarchy Process) is that elements relevant to decision are decomposed into goals, guidelines, programs and other levels, and on this basis, qualitative and quantitative analysis are made. Specifically, AHP is that a complex multiple-objective problem is regarded as a system, which the target is decomposed into several levels of multiple indicators; single ranking and the total ranking are calculated through the method of qualitative indicators fuzzy quantification.

In the following case, the task set has a target attack mission. Task allocation process is shown in the following.

Step 1 Post information

Task owner UUV query candidates that can provide service through task manager UUV, then task owner UUV could obtain candidate sets. Assuming that candidate sets have 10 candidates $\{UUV_1, UUV_2, \cdots, UUV_{10}\}$. Task owner starts to play the role of manager, which broadcasts bidding information to 10 candidates.

Step 2 Receive bidding information

Within the prescribed time limit, task manager has received 4 bidding information $\{UUV_1, UUV_2, UUV_3, UUV_5\}$. The capability information table of the bidders is as shown in Table 1.

Table 1 Parameters of bidder Agent

bidder agent	UUV_1	UUV_2	UUV_3	UUV_5
mission effectiveness u_1	62	85	71	83
promoting capacity u_2	55	86	83	78
spend consideration u_3	16	15	12	22
loads number u_4	1	2	3	2
completion time u_5	unknown	on time	timeout	unknown

Step 3 Bidders evaluation select

1) Establish hierarchical structure

A model diagram of the hierarchy analysis is constituted from the overall objective criteria to the first and two criteria, as shown in figure 3.

Target layer u: target attack mission tender

Criteria layer u_i: mission effectiveness u_1, promoting capacity u_2, spend consideration u_3, loads number u_4, completion time u_5.

Solution layer: $UUV_1, UUV_2, UUV_3, UUV_5$

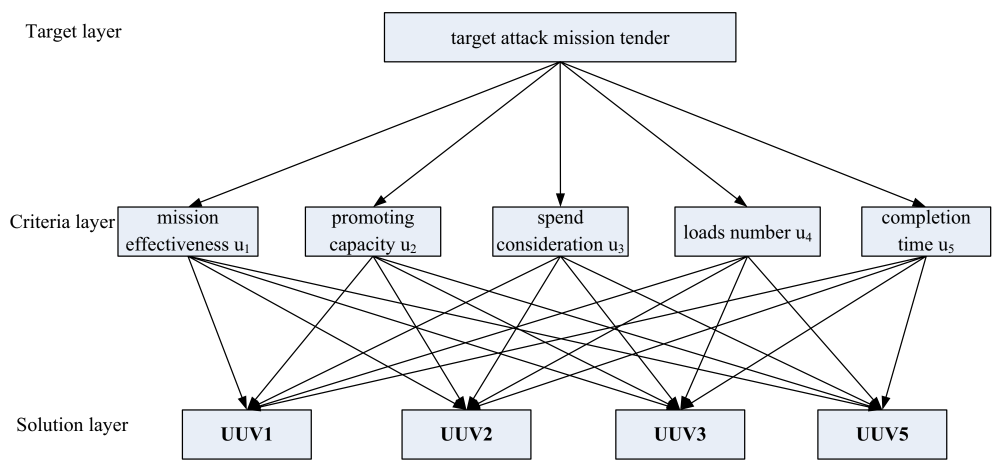


Figure 3 The model of AHP

2) Weight calculate and consistency check

Anglicizing the relationship between various factors, the importance degree of parameters is shown in Table 2.

Table 2 Important degree of parameters

Index	Task effectiveness	promoting capacity	spend consideration	loads number	completion time
Importance	extremely important	important	lower important	general important	unimportant
Numerical	1	0.875	0.75	0.625	0.5

r_k^{ij} is defined as the membership degree of indicator $U_i \in U$ to indicator $U_j \in U$ on the attribute y_k. If indicator U_i is better than indicator U_j, $r_k^{ij} > 0.5$, otherwise $r_k^{ij} < 0.5$; If indicator U_i is equal to indicator U_j, $r_k^{ij} = 0.5$, which $i, j = 1, 2, \cdots, m; k = 1, 2, \cdots, n$.

Random consistency comparative matrix C_R is generally used for detecting matrix consistent, which $C_R = (\lambda_{\max} - n) / [R_l (n-1)]$.

R_l is the random consistency index of comparative matrix, as shown in Table 3. Only $C_R < 0.1$, the comparative matrix has satisfactory consistency. It can be verified, comparative matrix directly meet the consistency condition.

Table 3 Random consistency indicators

n	3	4	5	6	7	8	9
R_l	0.52	0.89	1.12	1.26	1.36	1.41	1.46

Then we can get comparative matrix:

$$A = \begin{bmatrix} 0.5 & 0.625 & 0.75 & 0.875 & 0.875 \\ 0.375 & 0.5 & 0.625 & 0.75 & 0.75 \\ 0.25 & 0.375 & 0.5 & 0.625 & 0625 \\ 0.125 & 0.25 & 0.375 & 0.5 & 0.5 \\ 0.125 & 0.25 & 0.375 & 0.5 & 0.5 \end{bmatrix}.$$

The index of comparative matrix can reflect the important degree of mission effectiveness u_1, promoting capacity u_2, spend consideration u_3, completion time u_4 and loads number u_5.

Weight vector of each index can be calculated from this matrix. The normalized eigenvector of maximum eigenvalues $\lambda_{\max}$ of comparative matrix is the weight factors of each standard.

The relative weights of mission effectiveness u_1, promoting capacity u_2, spend consideration u_3, completion time u_4 and loads number u_5 can be described:

$$\omega_A = (0.29, 0.24, 0.19, 0.14, 0.14)^{\mathrm{T}}.$$

3) Expert groups score for suppliers

Expert groups score for suppliers as shown in Table 4.

Table 4 Expert groups score

Index	mission effectiveness u_1	promoting capacity u_2	spend consideration u_3	completion time u_4	loads number u_5
UUV_1	0.35	0.30	0.25	0.85	0.50
UUV_2	0.95	0.85	0.80	0.50	0.75
UUV_3	0.40	0.65	0.75	0.25	0.25
UUV_5	0.90	0.75	0.50	0.50	0.50

The evaluation vector of the index of mission income:

$$\begin{aligned}
\omega_{U1} &= 0.29\,(0.35, 0.95, 0.40, 0.90)^{\mathrm{T}} = (0.1015, 0.2755, 0.1160, 0.2610)^{\mathrm{T}}\,, \\
\omega_{U2} &= 0.24\,(0.30, 0.85, 0.65, 0.75)^{\mathrm{T}} = (0.0720, 0.2040, 0.1560, 0.1800)^{\mathrm{T}}\,, \\
\omega_{U3} &= 0.19\,(0.25, 0.80, 0.75, 0.50)^{\mathrm{T}} = (0.0475, 0.1520, 0.1425, 0.0950)^{\mathrm{T}}\,, \\
\omega_{U4} &= 0.14\,(0.85, 0.50, 0.25, 0.50)^{\mathrm{T}} = (0.1190, 0.0700, 0.0350, 0.0700)^{\mathrm{T}}\,, \\
\omega_{U5} &= 0.14\,(0.50, 0.75, 0.25, 0.50)^{\mathrm{T}} = (0.0700, 0.1050, 0.0350, 0.0700)^{\mathrm{T}}\,.
\end{aligned}$$

4) Calculating the combining weight of each layer elements relative to the target system, and sorting.

After determining evaluation vector of every factor, it can be calculated comprehensive evaluation vector S of index layer and the solution layer.

$$S = \begin{bmatrix} 0.1050 & 0.0720 & 0.4750 & 0.1190 & 0.0700 \\ 0.2755 & 0.2040 & 0.1520 & 0.0700 & 0.1050 \\ 0.1160 & 0.1560 & 0.1425 & 0.0350 & 0.0350 \\ 0.2610 & 0.1800 & 0.0950 & 0.0700 & 0.0700 \end{bmatrix}.$$

The synthetic weight vector ω can be calculated by the following:

$$\omega = S * \omega_A = (0.1644, 0.1822, 0.1080, 0.1565)^{\mathrm{T}}\,.$$

According to the analysis and calculations in the above, we can get

$$UUV_2 > UUV_1 > UUV_5 > UUV_3.$$

So UUV_2 has the maximum weight, if UUV_2 is selected, we can get the best comprehensive benefits.

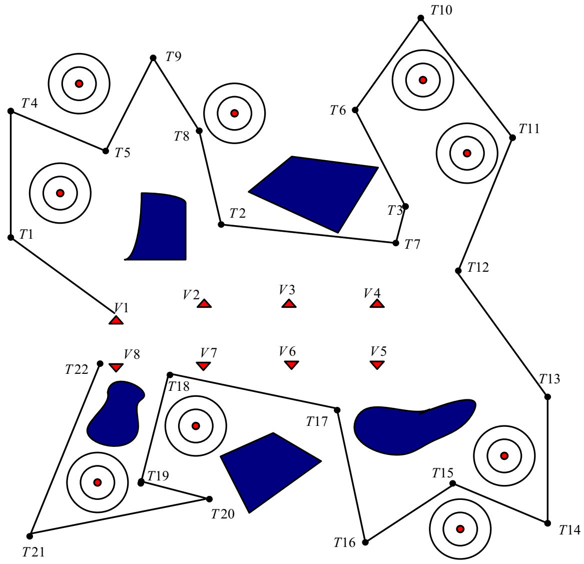
4 Simulation Analyses

In order to verify the effectiveness of the proposed task allocation algorithm, simulation system based on JADE platform is constructed, algorithmic software can simulate calculations in a CPU 2.2GHz, memory 2GB hardware platform. Assuming all UUVs are the same, and they have the ability to finish any task.

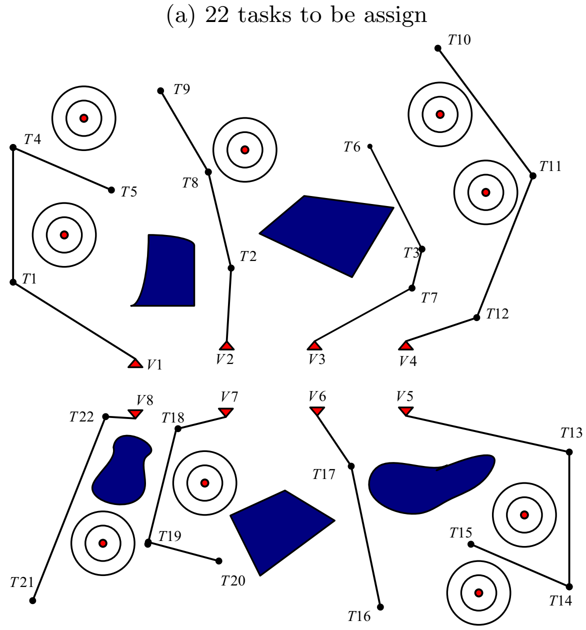
Formation constituted by 10 UUVs execute exploration mission to 22 goals, which is as shown in Figure 3.

UUV load constraints are three, in order words; the maximum number of tasks that can be performed for one UUV is three. Formation should make the overall effectiveness largest and time to complete tasks shortest by mutual cooperation, and make task distributed uniformly as much as possible in order to make full use of every UUV.

Tasks to be allocated distribute in the combat zone, as shown in Figure 4(a), which polygon areas are the obstacles, circular areas are enemy threats and its scope, which UUV should avoid these obstacles and threats. In order to verify the performance of the algorithm, first of all, all the tasks are assigned to V1, then formation achieve task assignment through bidding and tendering based on consultation, the result is as shown in Figure 4(b).



(a) 22 tasks to be assign



(b) the result of task allocation

Figure 4 The simulation experiment of task allocation

5 Theoretical Analysis

According to the task allocation process, time calculating formula can be proposed, as shown in the following:

$$t = 2\left([T_{c\min}, T_{c\max}] + T_{\text{Delay}} + N \cdot T_{\text{Transfer}}\right) + T_{\text{Dec1}} + T_{\text{Fusion}} + T_{\text{Dec2}},$$

which $T_{c\min}$ and $T_{c\max}$ are the maximum and minimum of communication time between task requesting UUV and receiving UUV. Because the spatial distribution of UUVs has extensiveness and uncertainty, it needs to use $T_{c\min}$ and $T_{c\max}$ to distinguish them. T_{Delay} is time of communication delay and waiting time, T_{Transfer} is the time of data transfer (Assuming data upload has the same time with download time); N is the number of UUV participated in coordinated operations; T_{Dec1} is the decision time of receiving UUV (Assuming different UUV have the same decision time); T_{Fusion} is the data fusion time of requesting UUV; T_{Dec2} is the decision time of requesting UUV, and assuming $T_{\mathrm{Dec2}} = (N-1)T_{\mathrm{Dec1}}$.

Then we can get, the total time of task assignment according to the above formula.

We can also get the following conclusion:

1) The total effectiveness analysis in task assignment.

The total effectiveness of task assignment grows rapidly with the auction, and it can reach a steady state after some rounds.

2) Time variation of each sub-tasks in one task assignment

The time of each sub-tasks in one task assignment is shorter and shorter with the conduct of the auction, this is due to the load limit constraint. If a UUV reaches the maximum load number, this UUV refuses to send any tender to requesting UUV, the time of communication and decision is shorted greatly.

3) Time variation of a fixed number of tasks

Time curve of a fixed number of 22 tasks can be divided into four stages. In the first stage, the number of UUV varies from 10 to 14, which the program execution time is essentially the same. In the second stage, the number of UUV varies from 14 to 40, which the program execution time decreases rapidly. In the third stage, the number of UUV varies from 40 to 50, which the program execution time is essentially the same, in which one UUV only is assigned a combat mission. In the last stage, the number of UUV varies from 50 to 60, which the program execution time does not increase but reduce; this is due to increase time of communication and decision.

4) Time variation of a fixed number of platform

The slope of the time curve of a fixed number of 10 UUVs becomes larger with the increase of the number of tasks. In other words, the amount of time increases rapidly because of the increase of the number of tasks.

6 Conclusion

With the help of multiple UCAV cooperative task control model, the mathematical model of multiple UUV cooperative task control is made. Variables related to decision are broken into goals, guidelines and programs levels by Analytical Hierarchy Process(AHP), on this basis, the command decision of multiple UUV task assignment is achieved. The correctness of task allocation algorithm is verified by case analysis. Calculation formulas for a task assignment' time is given. The changes of overall effectiveness in the process of task allocation are analyzed, the time changes of each sub task allocation time in one task assignment are analyzed, the time changes of the number of tasks and platforms respectively fixed in task allocation.

A further research direction:

1) Strengthen the research on collaborative side effects. Cooperation can bring two aspects effect. It has both positive and negative effects, especially in the conditions of poor communication between nodes. However in the description of a synergistic effect model, how the decision

quality, information quality correctly reflect two kinds of effect, is a topic worthy of in-depth study.

2) Research on path planning of underwater robot is the main research content of cooperative control of multiple UUV. It is also an unanswered problem that the tools of Voronoi diagram, Bayesian Networks and so on are used for researching static and dynamic path planning.

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