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Multi-AUV SOM task allocation algorithm considering initial orientation and ocean current environment

Key words: Autonomous underwater vehicles; Self-organizing neural networks; Azimuths; Ocean current

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Motivation (1/2)

1. Multi-AUV system task assignment and path planning is based on a certain algorithm to control AUVs, and each AUV navigates along the optimal path under certain conditions to reach the destinations.

2. Task assignment refers to assigning an AUV with the least energy consumption to the target point. Path planning technology refers to the path planning method for a single AUV after global task assignment. The fundamental problem is how to divide the whole task into several subtasks; thus, AUVs can move to their designated targets along the optimized paths while guaranteeing the least total consumption of a multi-AUV system.

Motivation (2/2)

Manual approach:

Weaknesses:

1. More time when processing a large number of targets;

2. Fatigue.

Automatic approach:

Strengths:

1. Time saving;

2. Minimization of human intensive workload;

Main idea

Multi-AUV task allocation and path planning algorithm based on an SOM

Due to the similarity between self-organizing map (SOM) neural networks and multi-task assignment, an SOM approach was applied to the path planning and task assignment of the multi-robot system. The algorithm is used mainly for dynamic classification of input vectors. The algorithm effectively resolves the problem of the number of AUVs and the number of unknown targets. Then the velocity synthesis approach combined with an SOM is applied to plan the shortest path for each AUV to visit the corresponding target in a dynamic environment.

Method (1/8)

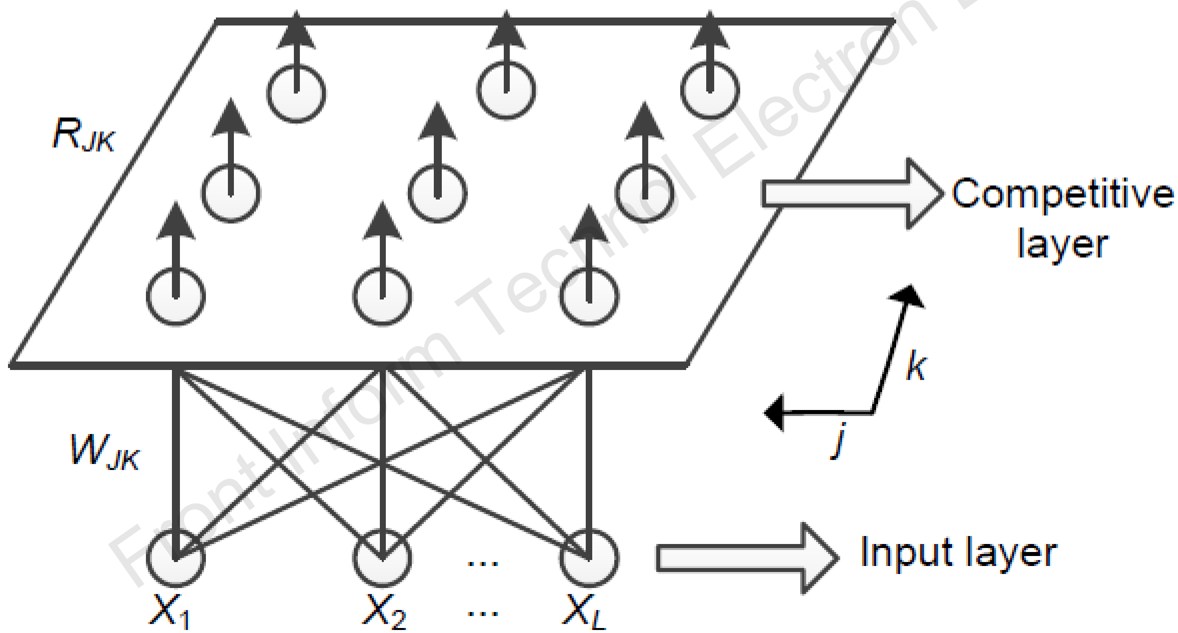

Fig. 2 SOM neural network structure in 3D workspace

Method (2/8)

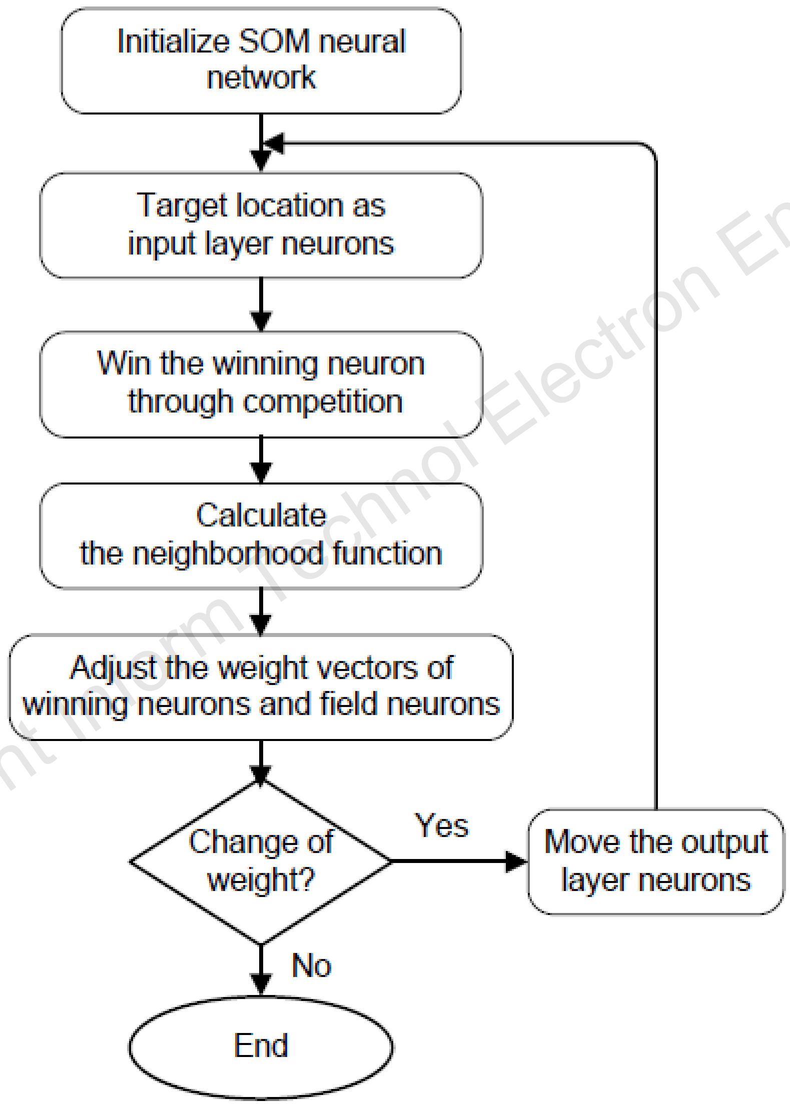

Fig. 3 SOM algorithm flow chart

Method (3/8)

Improved SOM task allocation and path planning algorithm in 2D plane

Angle=(θ_1, θ_2, …, θ_J) is the initial direction angle of the AUV, where J is the number of AUVs. θ_J, which is the direction angle of the J^{th} AUV at the initial moment, is the angle between x axis and the AUV at the initial moment.

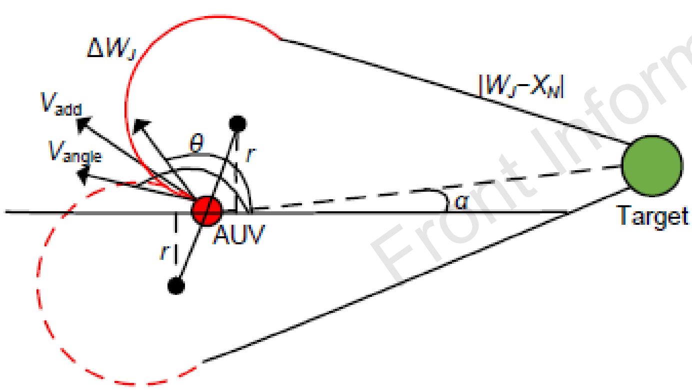

Fig. 4 Initial moment steering problem considering kinematic constraints

Green dot indicates the target point and red dot indicates the AUV. References to color refer to the online version of this figure

The angle between the target point and the AUV is expressed as $\boldsymbol{\alpha}$=(α_1, α_2, …, α_J), and x_N is the coordinate of the N^{th} target point in the Cartesian coordinate system. $\boldsymbol{W}$=(w_1, w_2, …, w_J) represents the coordinate of the AUV in the 2D plane, and ΔW_J indicates the distance navigated by the J^{th} AUV when γ=0. V_{add} is the direction angle of V_{angle} and θ, defined as

$$V_{\text{add}} = V_{\text{angle}} + \theta = \arctan \frac{R_{\text{V}} \sin V_{\text{angle}} + R \sin \theta}{R_{\text{V}} \cos V_{\text{angle}} + R \cos \theta}, \qquad (5)$$

Method (4/8)

Select the winner neuron

Parameter P controls the navigation load balancing among AUVs, and can be expressed as

$$P = (C_j - S)/(C + S), \quad (7)$$

where S represents the average navigating distance of each AUV in a multi-AUV system when completing a certain global task, and C the safe distance that the AUV can navigate without considering running out of energy. C_J (see the red and black lines in Fig. 4), representing the actual navigating distance of the J^{th} output neuron (AUV), is defined as

$$C_J = |W_J - x_N| + \Delta W_J. \quad (8)$$

Then the weight distance D_{KJN}, i.e., the turning distance of the J^{th} competitor neuron (AUV) from the K^{th} group when considering the initial orientation angle plus the Euclidean distance between the turning competing neuron (AUV) and the N^{th} input neuron (target point), is defined as

$$D_{KJN} = \begin{cases} C_J, & 0 \le C_J < C, \\ C_J(1+P), & C \le C_J < C_S, \\ 0, & C_S \le C_J, \end{cases} \quad (9)$$

Method (5/8)

Improved SOM task allocation and path planning algorithm in 3D plane

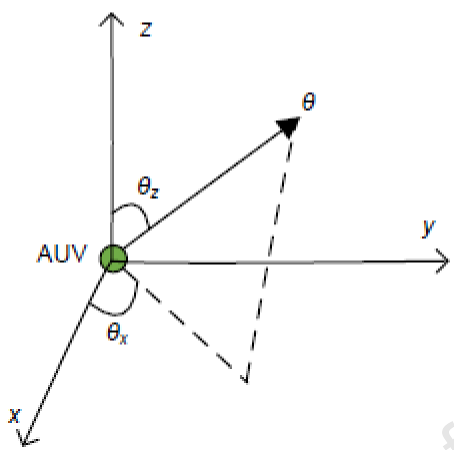

Fig. 5 Simplified model considering the initial angle
Green dot represents the AUV. θ represents the initial direction angle of the AUV, θ_x the angle between x-axis and the projection of the AUV on the x-o-y surface, and θ_z the angle between z-axis and θ. References to color refer to the online version of this figure

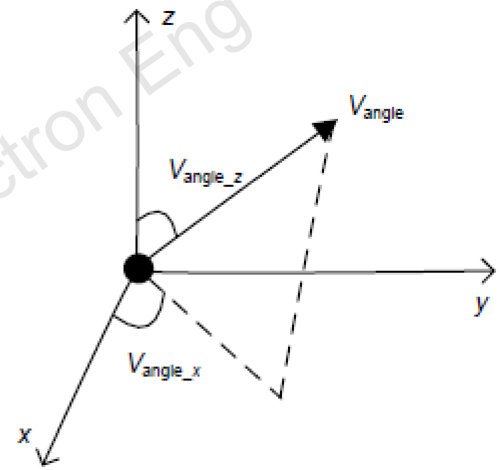

Fig. 6 Model considering the angle of the constant ocean current
Black dot represents the constant ocean current. V_{angle} represents the direction angle of the constant ocean current, V_{angle_x} the angle between x-axis and the projection of the constant ocean current on the x-o-y surface, and V_{angle_z} the angle between z-axis and V_{angle}. References to color refer to the online version of this figure

Method (6/8)

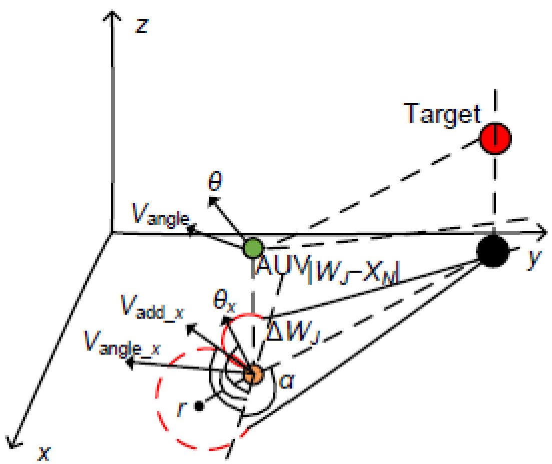

Fig. 7 Initial moment steering problem considering kinematic constraints on *x*-*o*-*y* plane current
Green dot represents the AUV, red dot represents the target dot, blue dot represents the projection of the AUV on the *x*-*o*-*y* surface, and black dot represents the projection of the target dot on the *x*-*o*-*y* surface. References to color refer to the online version of this figure

Fig. 7 shows the initial moment steering problem considering kinematic constraints on the *x*-*o*-*y* plane current. The initial direction angle of the AUV is known. $V_{\text{add\_}x}$ represents the vector direction angle of $V_{\text{angle\_}x}$ and θ_x, defined as

$$\begin{aligned} V_{\text{add\_}x} &= V_{\text{add\_}x} + \theta_x \\ &= \arctan \frac{R_{\text{V}} \sin V_{\text{angle\_}z} \sin V_{\text{angle\_}x} + R_x \sin \theta_x}{R_{\text{V}} \sin V_{\text{angle\_}z} \cos V_{\text{angle\_}x} + R_x \cos \theta_x}. \end{aligned} \quad (10)$$

Method (7/8)

According to the AUV horizontal thruster, R_x represents the speed of the AUV on the x-o-y surface. Define γ_x as

$$\gamma_x = V_{\text{add\_}x} - \alpha. \tag{11}$$

According to the AUV's horizontal thruster, the maximum steering angle of the AUV on the x-o-y plane and the steering radius are given. The AUV is steered in the decreasing direction of $|\gamma_x|$ until γ_x=0. The analysis method for the blue point navigation path is the same as that for 2D plane path planning. γ_z is defined as

$$\gamma_z = \frac{|T_z - R_z|}{R_{\text{V}} \cos V_{\text{angle\_}z} + R_{\text{VT}}}, \tag{12}$$

where T_z represents the z coordinate of target and R_z the z coordinate of AUV. According to the AUV's vertical thruster, R_{VT} represents the speed of the AUV on the z-axis. To ensure the normal navigation of the AUV, R_{VT} must be greater than $R_{\text{V}}\cos V_{\text{angle\_}z}$. The AUV is navigated until γ_x=1. ΔW_J indicates the actual navigated distance by the J^{th} AUV when γ_x=0 on the x-o-y plane. ΔW_J is the red solid line in Fig. 7. Parameter P controls the navigation load balancing among the AUVs (Yu and Zhu, 2017), and can be expressed as

$$P = (C_J - S)/(C + S), \tag{13}$$

where S represents the average navigating distance of each AUV in a multi-AUV system when completing a certain global task. C is the safe distance that AUV can navigate without considering running out of energy. C_J is defined as

$$C_J = |W_J - X_N| + \Delta W_J + |T_z - R_z|, \tag{14}$$

Method (8/8)

where C_J represents the actual navigating distance of the J^{th} output neuron (AUV), and C_S is the maximum distance that the AUV can navigate. Then the weight distance D_{KJN} is defined as

$$D_{KJN} = \begin{cases} C_J, & 0 \le C_J < C, \\ C_J(1+P), & C \le C_J < C_S, \\ 0, & C_S \le C_J. \end{cases} \quad (15)$$

By constantly adjusting the horizontal and vertical propellers, the AUV keeps moving closer to the target point and steering until the AUV and constant ocean current combine the speed direction of navigation points with the target point. Winning neurons (AUVs) are selected by considering the velocity and azimuths of constant ocean current, the turning distance of the AUV at the initial moment, and the distance between turning AUVs and target points. The AUV with the smallest weight distance D_{KJN} is the winning neuron. Then update the neighborhood of winning neurons, constantly adjusting weights until winning neurons reach the destinations.

Major results(1/2)

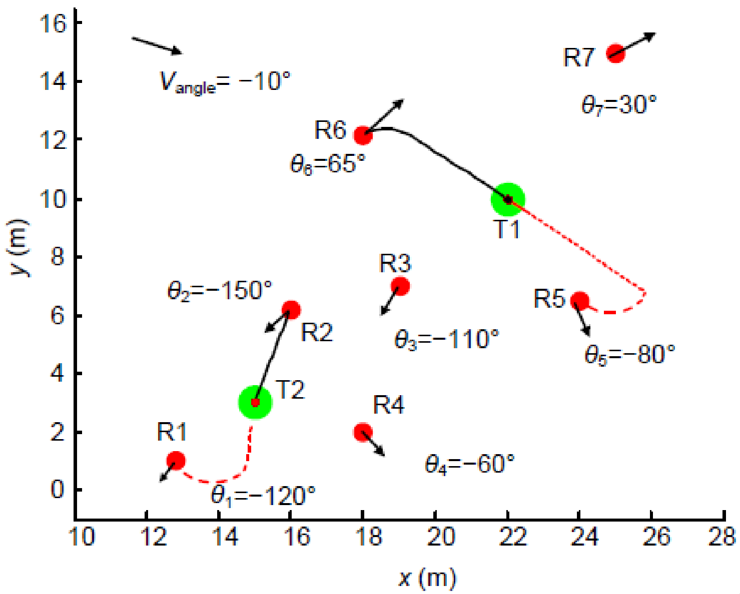

Fig. 8 Task assignment solution in a multi-AUV system when the number of AUVs exceeds the target number
Green dots represent targets, red dots represent AUVs, the black line indicates the moving path of the AUV in the improved algorithm, and the red dotted line indicates the moving path of the AUV in the traditional algorithm. References to color refer to the online version of this figure

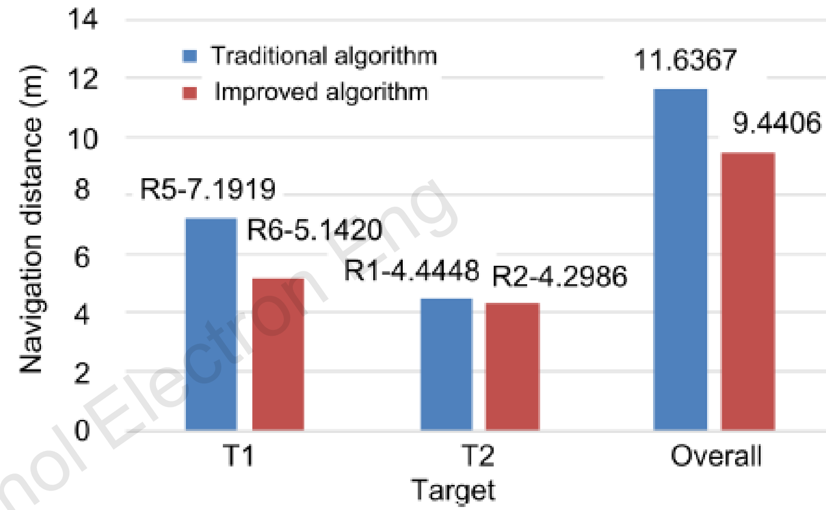

Fig. 9 Actual navigation distance of the AUV group to the target with constant ocean current when the number of AUVs exceeds the target number
References to color refer to the online version of this figure

The sum navigating distances of the AUV group for T1 and T2 are 11.6367 m and 9.4406 m in the traditional self-organizing algorithm and the improved self-organizing algorithm, respectively. The improved algorithm saves 18.87% of the total navigation length compared with the traditional algorithm. As shown in Fig. 9, the improved algorithm saves energy for the AUV group.

Major results (2/2)

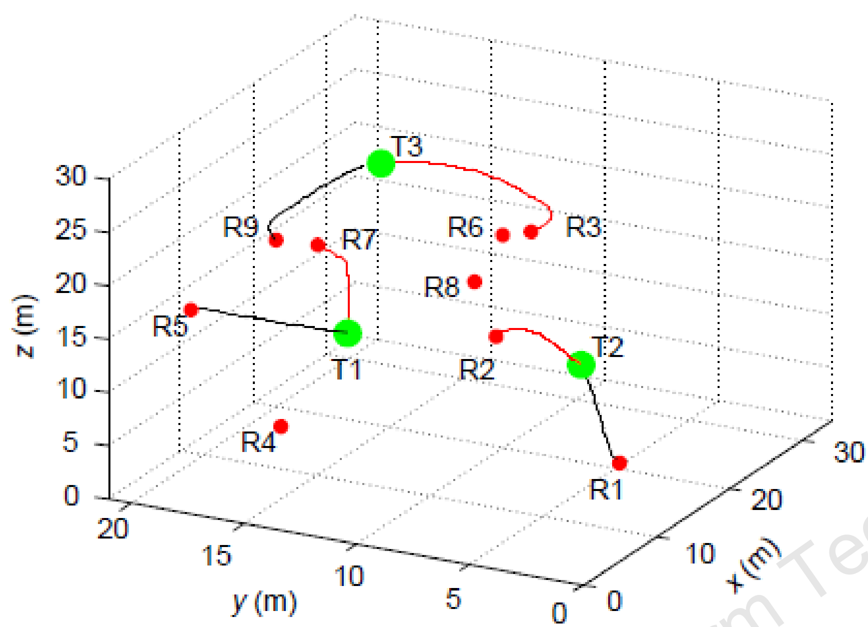

Fig. 13 Task assignment solution in a multi-robot system when the number of AUVs exceeds the number of targets
Green dots represent targets, red dots represent AUVs, the red line indicates the moving path of AUVs in the traditional algorithm, and the black line indicates the moving path of AUVs in the improved algorithm. References to color refer to the online version of this figure

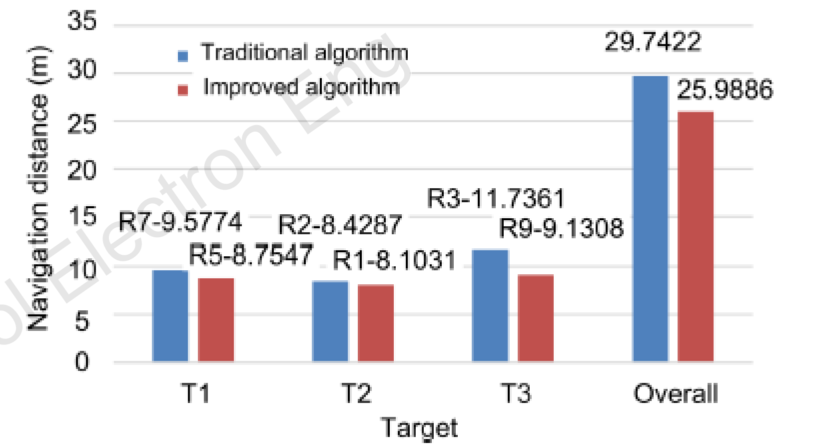

Fig. 14 Actual navigation distance of the AUV group to the target with constant ocean current when the number of AUVs exceeds that of targets in 3D plane
References to color refer to the online version of this figure

The sum navigation distances of the AUV group for T1, T2, and T3 are 29.7422 and 25.9886 m in the traditional self-organizing algorithm and the improved self-organizing algorithm, respectively. The improved algorithm saves 12.62% of the total navigation length compared with the traditional algorithm.

Conclusions

In this paper, the constant ocean current, kinematic constraints, and different azimuths at the initial time have been considered during multi-AUV task assignment and path planning. A novel SOM task assignment and path planning algorithm has been proposed. In the improved self-organizing map algorithm, an AUV not only successfully traverses to the target point, but also has the shortest navigation path and saves energy for the AUV group. This method can be extended to complex situations, such as moving obstacles.