# Collision Free Formation Control for Multiple Autonomous Underwater Vehicles

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*Abstract:* **An architecture for collision free formation control of multiple autonomous underwater vehicles is proposed in this paper. Based upon blackboard communication, the architecture includes communication, motion control and environment interacting modules. Orderly-Quaternion sets and control matrix are defined for the design of accurate formation geometry. Formation changing rules are proposed based on sensor information at first, and control matrix and artificial potential method are then utilized in formation reconfiguration. Finally the proposed approach is verified by a simulation of a swarm of 8 AUV's moving through a constrained environment.**

## I. INTRODUCTION

Autonomous underwater vehicles (AUV's) have been an increasingly important means for ocean exploration and exploitation. However, it's difficult for a single AUV to adapt to the unknown and hostile underwater environment. For complex tasks, multiple AUV's are required due to higher efficiency and stronger robustness to single vehicle failures. Through formation, autonomous underwater vehicles can coordinate and cooperate effectively. However, in unstructured, unknown, and dynamic environments, the formation will be disturbed by underwater obstacles. When moving in a constrained environment, a swarm of AUV's must be able to avoid colliding with underwater obstacles. Therefore collision free formation control is appealed.

A collision free formation control scheme enables a swarm of AUV's to reconfigure its formation according to changes of underwater environment[5].

The problem of collision free formation control was proposed by .Parker [6]. Most research work are about collision free formation control of multiple unmanned air vehicles [7] [8].To the best of our knowledge, the problem of collision free formation control for multiple AUV's is not well studied yet.

Based upon a blackboard-communication architecture, collision free formation control of multiple AUV's is studied in this paper. Formation changing rules are proposed based on sensor information at first, and control matrix and artificial potential method are then utilized in formation reconfiguration. Finally the proposed approach is verified by a simulation of a swarm of 8 AUV's moving through a constrained environment.

## II. BLACKBOARD COMMUNICATION-BASED ARCHITECTURE

Multi-robot system architecture can affect the entire system performance. According to the classic MAS (Multi-Agent-System) architecture, the system can generally be divided into the blackboard architecture [9], the network architecture [10] and the union architecture [11] .

As shown in Figure 1, the blackboard communication-based system architecture, which includes communication, motion control and environment interacting modules, is applied.

Within the communication module, TCP/IP protocol is applied to accomplish communication task: each AUV exchanges information with the shared-blackboard area. While the information sent to the blackboard includes the positions of obstacles, the information received from the blackboard area includes sub-goal position, status information and etc. The module can be carried out by the CAUVsTeam Class through the following functions:

- void SetInfoOnBlackBoard(CPoint pt, double falf, bool bLeaderArrived)
- bool GetInfoOnBlackBoard(CPoint *pt, double *falf)

The motion control module involves formation behavior and kinematics equations. Formation behaviors consist of obstacle avoiding, formation generating, keeping & reconfiguration. The kinematic equations are of two-dimensional planar motions since only constant depth motions are considered currently.

In the environment-interacting module, forward-looking sonar is adopted to detect the ambient environment to gain some data about obstacles and other AUVs. Moreover, reactive control is adopted on the behavioral interaction layer.

## III. COLLISION FREE FORMATION CONTROL

### A. Formation Design

Orderly-Quaternion sets and controlling matrix are utilized to design the accurate formation geometry. While the orderly-quaternion sets are designed to confirm the adjacent verges between the neighbor AUV's, the control matrix is derived to ascertain the logic relations between each AUV among formation teams. The orderly-quaternion sets are defined as follows:

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$$E_N = \{(V_1, V_2, R_{12}, \sigma_{12}), (V_2, V_3, R_{23}, \sigma_{23}), \ldots, (V_{N-1}, V_N, R_{N-1\ N}, \sigma_{N-1\ N})\} \quad (1)$$

where $E_N, V_i, R_{ij}, \sigma_{ij}$ represent orderly-quaternion sets, nodes, distance and headings between two adjacent nodes, respectively.

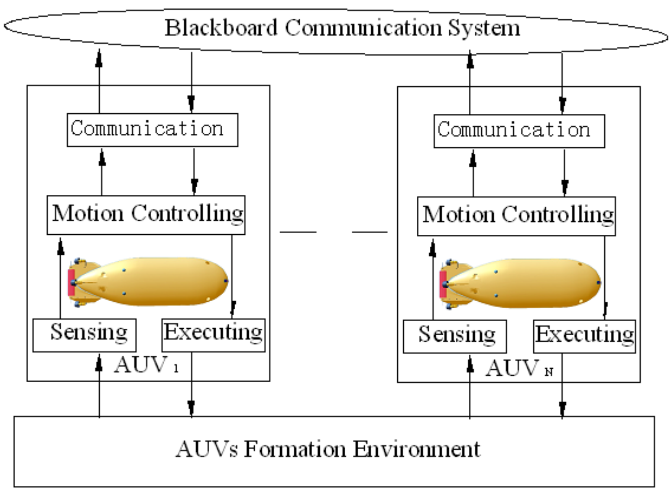


Figure1:Blackboard communication-based architecture

### B. Collision Free Formation Control

The formation type must rely on forward-looking sonar information. The control matrix is used to implement formation changing among several types. The changing rules are listed as follows:

(1) If the obstacles detected by sonar don't threaten AUVs, then AUVs will keep the original formation. Also if only one AUV detects some dangerous obstacles, then the formation should not be changed.

(2) If there are two or more AUVs are in danger, then the formation will make some adjustment to identify the threatened conditions, and the new type is compacted. We can define this issue as same-side rule.

(3) Another case is other-side rule. if $d_{Detect} < d_{FW}$, then the formation will change into another type; if $d_{Detect} \geq d_{FW}$, then the formation will not change, where formation width and formation detecting distance are defined as follows:

$$d_{FW} = d_{safe} + d_{AUVs} + d_{safe} \quad (2)$$

$$d_{Detect} = \sqrt{(x_L - x_R)^2 + (y_L - y_R)^2} \quad (3)$$

where $d_{safe}$ and $d_{AUVs}$ representing the minimum safety distance of AUV, and distance between two AUVs respectively, and $A(X_L, Y_L), B(X_R, Y_R)$ representing the coordinates of the left and right obstacles detected, respectively.

As shown in Fig.2, for example, the original V-type formation will be changed into a Y-type formation, since No.4 and No.5 AUV's are threatened by the obstacles (black hexagons).

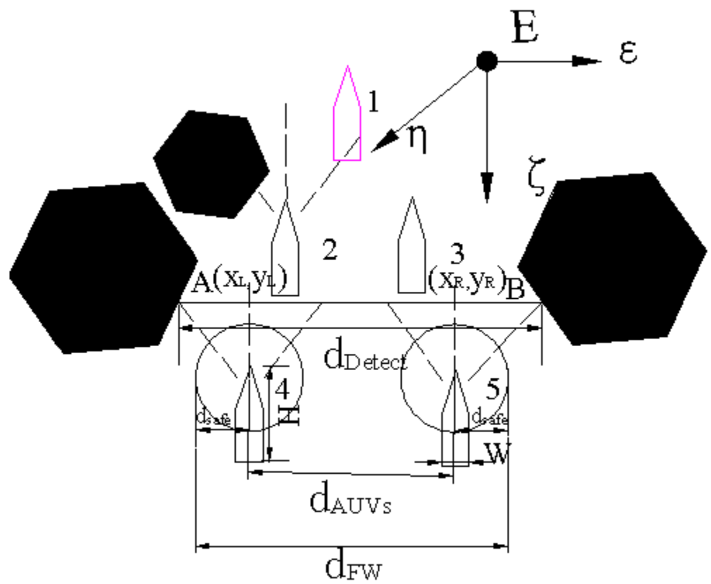


Figure 2 Schematic of collision free formation control

### C. Formation Reconfiguration

Formation reconfiguration for the AUVs' system is illustrated in Fig. 3. The affinity function and the exclusive function are defined in (4) and (5), respectively.

$$F_{PA} = -\exp(\sin\phi_{jj'}) \cdot \nabla P_{PA} \quad (4)$$

$$P_{PA} = \frac{1}{2}\rho_{PA} \cdot \left\| d_{jj'} \right\|^2 \quad , \forall j = 1, 2, \cdots, N-1 \quad (5)$$

Where

$\| d_{jj'} \|$ : distance between actual and ideal position

$$\| d_{jj'} \| = \sqrt{(x_j - x_{j'})^2 + (y_j - y_{j'})^2} \quad (6)$$

$\phi_{jj'}$ : heading error between actual and ideal heading

$$\phi_{jj'} = \left| \alpha_j - \alpha_{j'} \right| \quad (7)$$

$\rho_{PA}$ : positive gain for the sub-target point to be reached

$d$ : motion vector for each AUV

$\alpha$ : heading for each AUV.

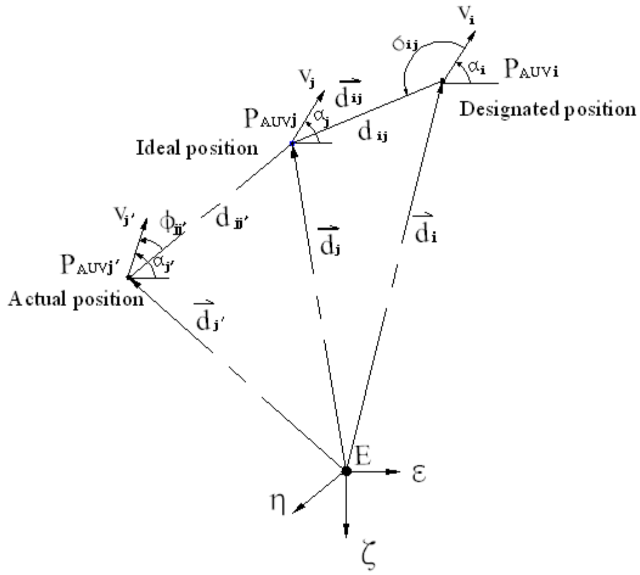

Figure 3 Schematic of formation reconfiguration

## IV. SIMULATION RESULTS

The strategy proposed can be embedded into the motion control simulation platform for multiple AUVs' system. Windows-based platform are developed by VC + + to verify the effcetiveness of the method.

In the formation case, the simulation region is 2-dimensional environment by 1000 × 1000 meters, a swarm of 8 AUV's moving through a constrained environment is considered. The original formation is circle type with an inter-AUV distance of 45 meters. The positions of the starting point S and target point G are [120,130] and [906,777], respectively.

A few snap shots of swarm motion are shown in Fig.4-7. It can be seen for the swarm of AUV's to move through the constrained area, its formation changes from initial formation to the final formation in the following sequence: circular type formation (Fig.4), V-type formation (Fig. 5), Y-type formation (Fig 6) and line-type formation (Fig. 7).

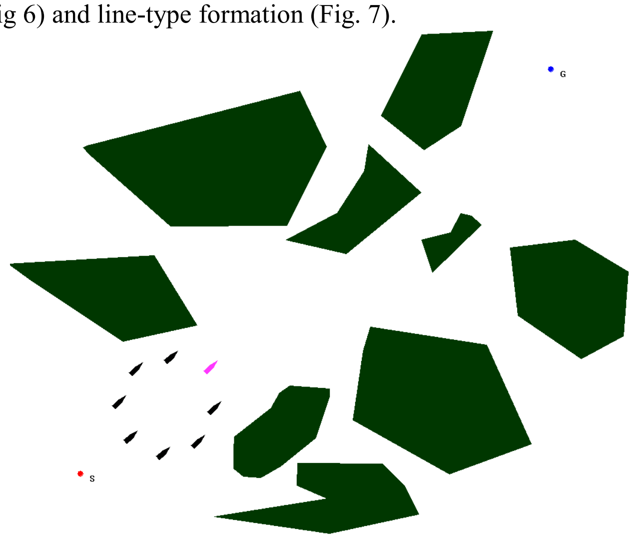

Figure 4 The initial circle type formation

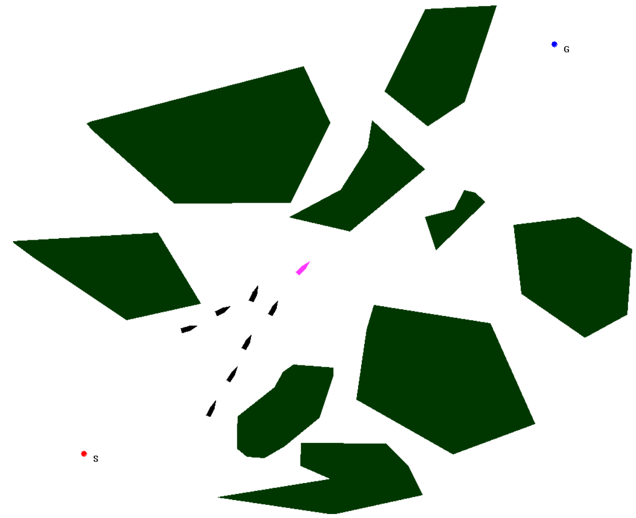

Figure 5 Formation converted to V-type

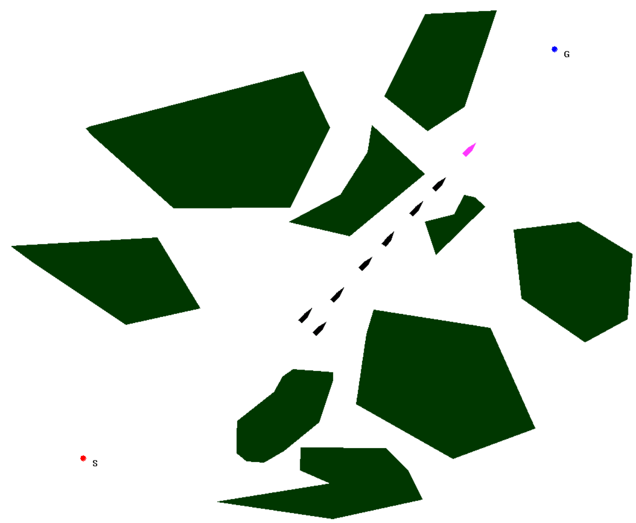

Figure 6 Formation converted to Y-type

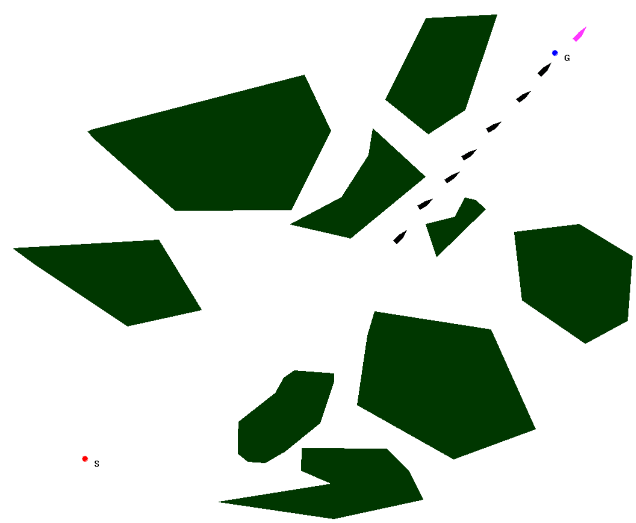

Figure 7 Formation converted to line type

## V. CONCLUSION

In this paper, we have discussed strategies for controlling formations of multiple AUV's using algorithms from blackboard communication based architecture and orderly-quaternion sets and control matrix .For a swarm AUV's to achieve collision free formation reconfiguration within a constrained underwater environment, we have developed the idea of a transition strategy. Based upon blackboard communication, the architecture includes communication, motion control and environment interacting modules. Orderly-Quaternion sets and control matrix are defined for the design of accurate formation geometry. Formation changing rules is brought forth based on sensor information and control matrix, and artificial potential method is then utilized in formation reconfiguration. We verify the methodology with a simulation of a swarm of 8 AUVs moving through a constrained environment.

Future work will be focused on collision free formation control of multiple AUV's within dynamic environments.

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