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Hybrid Coordination Strategy of a Group of Cooperating Autonomous Underwater Vehicles

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Abstract: In the underwater environment, the needs of data acquisition have significantly increased over the last decades. As electromagnetic waves show poor propagation in sea water, acoustical sensing is generally preferred. However, the emergence of small and low cost autonomous underwater vehicles (AUV) allow for rethinking the underwater use of optical sensors. Their small coverage can be significantly improved by using a fleet of coordinated underwater robots. This paper presents a strategy to coordinate a group of robots in order to systematically survey the seabed and detect small objects or singularities. The proposed hybrid coordination strategy is based on two main modes. The first mode relies on a swarm algorithm to organize the team in geometrical formation. In the second mode, the group formation is maintained using a hierarchical coordination. A finite state machine controls the high level hybrid strategy by defining the appropriate coordination mode according to the evolution of the mission. Before the sea validation, the behavior and the performance of the hybrid coordination strategy are first evaluated in simulation. The control of individual robots relies on visual servoing, implemented with the OpenCV library, and the simulation tool is based on Blender software. The dynamics of the robots has been implemented in a realistic way in Blender using the Bullet solver and the estimated hydrodynamic coefficients. This paper presents and discusses the preliminary results of the hybrid coordination strategy applied on a fleet of 3 AUVs.

Keywords: Multi-robot cooperation, coordination, formation control, control architectures, visual control simulator.

1. INTRODUCTION

In the last decades, the systematic search for small objects on the seabed is an activity in development. For these applications, the reference sensor is the imaging sonar. Indeed, for highly cluttered areas, for very small objects or for materials whose acoustic impedance is similar to water, the imaging sonar may be inappropriate. In this case, incoherent optics is a good alternative and the underwater video camera is an interesting sensor. Low cost and low power consumption are the main advantages of underwater video cameras. Their main inconvenient is a very limited operating range in sea water, but this can be overcome by using multiple cameras deployed on a coordinated fleet of autonomous underwater robots (AUV). The optical sensing of the seabed with a group of robots implies short distances between them. Therefore, incoherent optics can be used for additional purposes : robot control by visual servoing and communication between them (Drevelle et al. [2013]). However, when some robots are too far to see each other, conventional acoustic communication brings them back to visual distance. The study on using multiple robots with cooperative behaviors to achieve a global and unique mission has led to several methods of coordination. Actually, the swarm behavior is a coordination method that relies on rules of local interaction between robots in order to give to the whole fleet the required behavior (Cao et al. [2006]), (Balch et al. [1999]). This approach is well suited to distributed control (Yamaguchi et al. [2001]). However, a complex mission can be decomposed into sub-tasks dedicated to each robot of the fleet. A leader controls the execution of the sub-tasks. This corresponds to a centralized or hierarchical control (S. Y Chiem [2004]). By using a fleet of AUVs to perform an undersea survey mission, it clearly appears that different phases of the mission require different coordination methods. To better adapt the coordination method to a given phase of a mission, a new hybrid coordination strategy is proposed by alternating between swarm and hierarchical control methods.

2. HYBRID COORDINATION STRATEGY

The proposed hybrid coordination strategy contains two main modes. The first mode consists in organizing the fleet of robots in a geometric formation (Balch and Hybinette [2000]), (Li et al. [2009]). This mode is particularly suitable for the start of the mission after a random launch of the robots during the mission. It is also adapted when, for some external reason, the formation collapses. In the second mode, the formation must be maintained so that the group of robots performs the acquisition of underwater data. These two main modes, which can be called "building the formation" and "surveying the seabed", do not require

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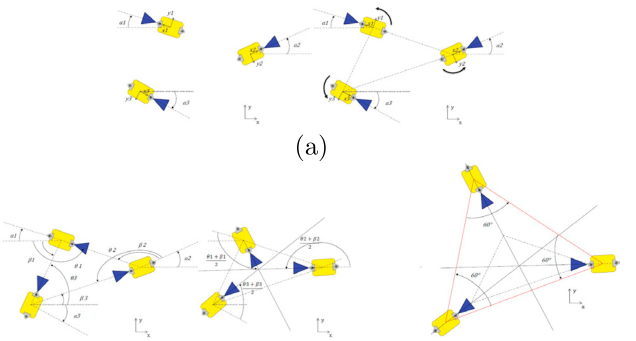

(a)

(b) (c)

Fig. 1. The three steps of the "building the formation" mode.

the same type of coordination. The first mode has to organize the fleet in a geometrical formation starting with robots at random locations and a swarm behavior is well suited for this task. When all robots have built the geometrical formation, a leader is elected and it hierarchically controls the acquisition of the data by the other robots. Each different mode can be considered as a state. Events can be associated with the changes of formation status. Based on these assumptions, the top level (hybrid) coordination strategy of the fleet is achieved by a finite state machine (FSM).(Fig.2)

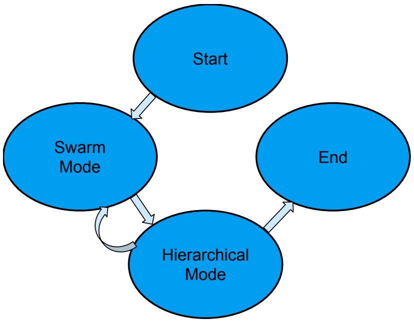


Fig. 2. Finite state machine.

The objective of the "building the formation" mode is to align the robots according to a given geometrical configuration. To illustrate this mode, a fleet of 3 robots making a triangular or V-shaped formation is considered (S. Y Chiem [2004]), (Yamaguchi et al. [2001]). Each robot executes the same task, decomposed in three steps. During the first step, a search for the two neighbors is conducted by rotating around the z axis (Fig.1(a)) and recording the corresponding angles. In the second step, each robot tries to align its heading with the bisection between the angles of the two detected neighbors (β_i,θ_i) (Fig.1(b)).

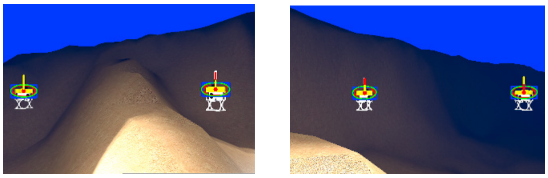
$$heading = \begin{cases} (\beta_i - \theta_i)/2 + min(\beta_i, \theta_i), & if \gamma_i \leq \Pi \\ (\beta_i - \theta_i)/2 + max(\beta_i, \theta_i), & if \gamma_i \geq \Pi \end{cases} \quad (1)$$

where

$$\gamma_i = |\theta_i - \beta_i| \in [0, 2\Pi] \quad (2)$$

In the last step, each robot increases or decreases its field of view to see its two neighbors at a given location on its video image. (Fig.1(c)).

To generalize this method, the cardinality of the robot's team increases from three to five. Based on the work of Lee and Chong [2009], the coordination of the team requires two additional steps. The first is to establish a local coordinate system for the group and the second consists in allocating an identifier (ID) for every robot.


(a) first robot camera (b) second robot camera

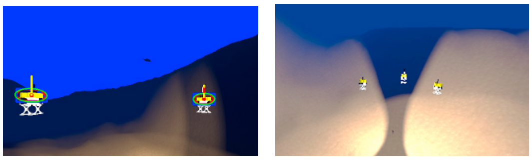

(c) third robot camera (d) global view

Fig. 3. The setting formation phase.

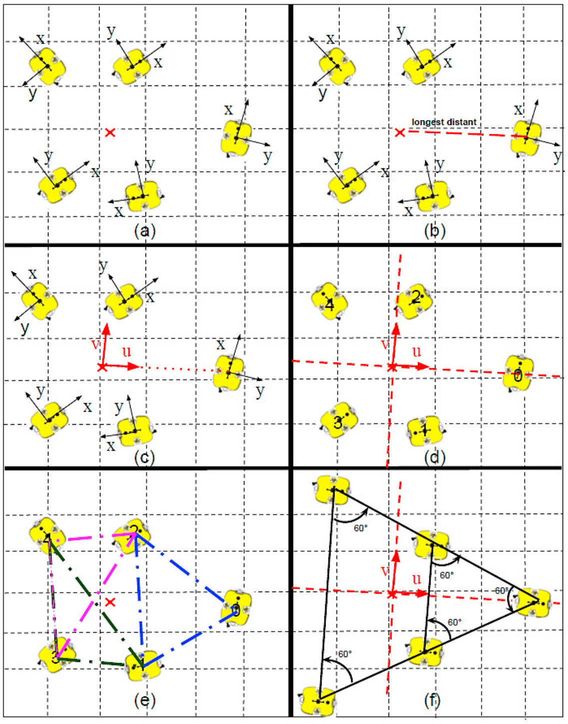


Fig. 4. Steps of "building the formation"mode for five robots, (a) searching neighbors, (b) determination of the center point, (c) definition of the common coordinate system, (d) ID allocation, (e) setting formation with corresponding neighbors, (f) stable V formation

The reference point for the local coordinate system is the centroid of the coordinates of the members of the team (Fig.4(a)). A common direction is defined by drawing a line from centroid extending to the position of the farthest member (Fig.4(b)). The common direction defines the horizontal axis (u-axis).The vertical axis (v-axis)can be defined by rotating (u-axis) 90 degrees counter clockwise (Fig.4(c)). Using their location defined in the local (u,v) coordinate system, IDs are assigned to all the members according to their distance to the centroid of the team.