Market Based Multiple AUVs Cooperation

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Abstract:

Oceanographic survey, or other similarly applications require using AUV teams, which demand for efficiency, diversity of scheme, enough robustness and other features which single AUV system cannot provide. In this paper, we discuss the cooperation mechanism for AUV team's control by introducing the "Market" based cooperation methods. Based on "Market" a multi-AUV system controller, $MAUVS-CS$, is implemented and tested in the new simulation environment. Two typical multi-AUV applications (the minefield reconnaissance and the MTSP) are realized and simulated with the controller.

Introduction

Large-scale oceanographic survey, military mines sweeping and other similarly underwater application systems require for the multiple-AUV systems. For single robot system cannot meet these demands for the reasons of efficiency, diversity, costs and robustness etc. An example of these applications is the ASON [5], which aims at building an open, flexible autonomous oceanographic survey system based on multiple AUVs.

But how to effectively, optimally allocate the tasks and resources to each AUV in the team? This is a problem of dynamic resource-allocation, one of the key technologies of the multi-AUV control system.

For small group of AUVs, the central coordination methods will have more optimal and have confirmative solutions. The SAMON [6] and the CoDA [7] are examples of such systems. Both systems are the two-level hierarchically organized AOSN networks; the role of each AUV is predefined, and the tasks are allocated in a fixed manner. But when more robots are present or the tasks cannot be arranged beforehand, these systems will be less effective and less flexible.

In this paper we adopt the decentralized coordination method for the dynamical task allocation and system optimization. A "Market" based AUV cooperation mechanism is introduced here. Based on the mechanism we have developed a new completely distributed AUV controller, MAUVS-CS, which is built on the S^2BHCA architecture. Simulation tests are carried out for the validation of the new cooperation mechanism.

Economy Approach to Multi-AUV Coordination

The "Market" approach is a kind of economy method that is inspired by the daily economy activities happening around us. These methods are widely used in the coordination of MAS or DAI.

The Contact Net Protocol or CNP [1,2] initially proposed by Smith is one of the widely accepted coordination mechanisms. It simulates the microscopic economy activities, auction-bid, in human society aiming to allocate tasks or resources dynamically and freely. At the same time, from the view of the ecology of computing, Miller [4] believes that the market is the most complete computational ecology model in the nature. Despite the fact that individuals in the economy act only to advance their own self-interests, the aggregate effect is a highly productive society. We follow their ideas and methods to constructing our multi-AUV system.

Gerky's MURDOCH [8] is a completely distributed real robot team control systems. It is a variant of the CNP, using a simple one-round auction to investigate practical methods for allocating tasks to groups of autonomous and heterogeneous physical robots. Once a task is allocated, the auctioneer will monitor the performance of the task, and may reassign it to other robot if the performer cannot complete the task in the limit time. Dias.'s "Free Market" [3] is another economy model for the robot team control and the task allocation. He uses a iterated publish/subscribe coordination model for global optimizing; multiple-round auctions may occurs for one task. So every robot in team can be the "buyer" or "seller" for a "goods (task)". The iterated auctions for global optimum will cause communication overhead if the price of task is ill defined, though the system may be dynamically adaptive.

Our "Market" approach is also an economy model based method for multi-robot task allocation and coordination, similar to that of Dias and Gerky. Here the deference is the price strategy and the iteration strategy. We use the seller-defined price at a fixed expected profit, and limited iteration for the faster global constringency and the decrease of communication.

The Market

Let's consider a team of AUV for a particular set of tasks, $taskset = \{task_i\}$; here we do not care about the task decomposition, assuming that all task are pre-decomposed. The task assignment is not obliged; the assignment can be achieved by a trade of the task between AUVs. In another word, one AUV can "sell" the tasks to or "buy" the ones from others at a preferred price; and every AUV in the team is modeled as a self-interested agent, making its own profits by coordination with others. Thus the whole team then could be regarded as an economy, and the goal is to minimize the overall costs, when each AUV aims to maximize its own profit.

The task's cost stands for the resources that the AUV will consume to accomplish the task; it can be the energy, the time and others that the system designer is interested in. We define the function, $m_j \cos t(task_i)$, as the cost that the j th member in team will pay out when it completes the i th task, and $m_j \cos t'(task_i)$ as the corresponding estimated value before executing. So the whole team's cost $t \cos t(taskset)$ can be calculate as below:

$$t \cos t(taskset) = \sum m_j \cos t(task_i)$$

In the task allocation process we expect to decrease the $t \cos t(taskset)$ as much as possible in order to get the optimal result.

The optimal solution can be achieved by dynamically exchanging the tasks between AUVs using the auction methods. Before performing the task assigned, the AUV can announce the auction and "sell" the tasks it holds to any others at a preferred price. This price plays an important role in the coordination process. The seller and the buyer have deferent expectance of the price, each wants to gain more profit from the trade. But for the seller the price must be lower than the estimated cost of the task minus the minimal expected selling profit ($sellprofit$):

$$m_s price(task_i) = m_s \cos t'(task_i) - sellprofit . \quad [1]$$

And for any buyer, the price should be greater than its estimated cost plus the buying profit ($buyprofit$):

$$m_b price(task_i) = m_b \cos t'(task_i) + buyprofit \quad [2]$$

Apparently the condition that a trade is possible is:

$$m_s price(task_i) \ge m_b price(task_i) \quad [3]$$

And the actual price can be adjusted to the average of both prices:

$$\Pr ice = (m_b price(task_i) + m_s price(task_i)) \div 2 . \quad [4]$$

If the trade is successful both sides get the incomes:

for sellers;

$$m_s receive(task_i) = m_s price(task_i) - price(task_i)$$
$$and \;\; m_s receive(task_i) \ge sellprofit$$

for buyers:

$$m_b receive(task_i) = price(task_i) - m_b \cos t(task_i)$$
$$and \;\; m_b receive(task_i) \ge buyprofit$$

Since modeled as a self-interested agent, each AUV always try to get more profits by "buying" or "selling" the task. At the same time the overall team cost, $t\cos t(taskset)$, will decrease with the task's movement from the higher cost AUV to the lower ones. The auction occurs dynamically whenever the task holder considers the situation is appropriate.

The S^2BHCA Based Controller

We have realized the "Market" coordination mechanism based on the S^2BHCA architecture, which is specially designed for multi-AUV coordination control. The primary system implemented calls the $MAUS-CS$ (Multi-AUV System–Control System).

The S^2BHCA is a three-layered autonomous control architecture, figure [1], including the low level hardware functional layer, reactive skill control layer and the task control layer standing for hardware control, behavioral reactive control and deliberative control respectively. The core idea is the concept of "Skill", which aim at bridging the gape between reactive and deliberative control. The concept of "Skill" resides in both task control layer and reactive skill control layer, having deferent form in deferent layers. In task control layer, a skill is a cell of the meta-level reasoning for either building more complex missions or performing the meta-level coordination among AUVs. While in reactive skill control layer it is a behavior-based reactive controller, a behavior networks, which gives the AUV fast reactiveness and "emergent" intelligence. Another feature of the skill is the ability of running in two deferent modes: the real mode and the simulation mode, which allows the AUV to estimate the skill-based task cost before executing. So in the skill control layer, there may have three running modules: the skill in real mode, the committed tasks queue in simulation mode, and a proposed task for evaluation also in simulation mode.

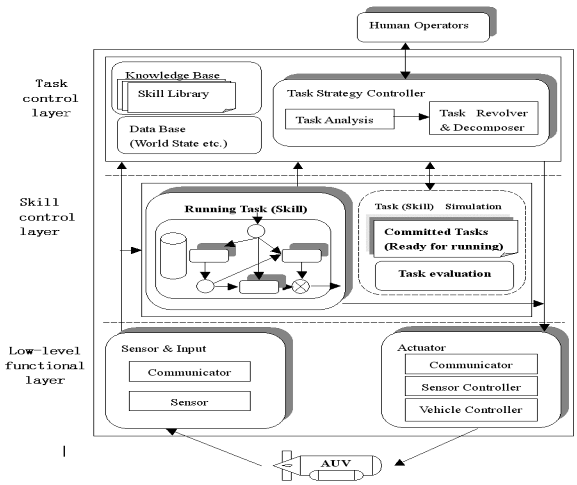

Figure 1. The S^2BHCA based Controller

The task level controller determines which skill should be selected to execute in order to achieve the goal that operator gives or suggested by other AUVs. Tasks that must be carried out at this AUV locally will invoke the specified skill running in real mode immediately. The optional tasks that can be dynamically allocated among AUVs will experience a little more complex process. The optional task is firstly submitted as a proposed task in the simulation mode for evaluation, and then it will be accepted and queued in the committed task queue or rejected it according the simulation results. One of the committed tasks will be carry out in real mode if the current running task completes.

The Market Based Multi-AUV Cooperation

The $MAUVS-CS$ controller is built atop of S^2BHCA, equipped with several task-oriented skills and a simple knowledge based meta-level controller. The realized skills include: the Idle Skill, the Rally-At Skill and the Search-Area Skill, which stand for three deferent ability of the AUV.

1) Heterogeneous AUV cooperation. Though the AUV may have deferent skills according to deferent hardware configuration, the market-based coordination in the meta-level control only cares about the profits that the trade of tasks brings atop of the concept of skills. Detailed tasks cooperation will be processed inside the behavioral controller, which relies on more accurate models. An example is the AUV's team formation control. The role of team leader can be assigned to the AUV having more knowledge and resource by the auction, while the actual task execution is carried out inside the Rally-At. Thereby heterogeneous cooperation can be achieved.

2) Auction process. The auction is the key of

the whole coordination process, in which the optimal task allocation is achieved. Each AUV can be the seller or the buyer at deferent time, and the tasks are pre-decomposed for convenience. And for the simplification of problems, we assume only one role that the AUV can act as simultaneously and the auction process is one-round fashion. One-round auction process consists of 6 steps carried out at both the seller and the buyer:

i) Seller: Evaluates the task it holds or assigned by operator. The task is running in the simulation mode for cost estimation; the AUV may be busy in completing a real running-mode task at the same time.

ii) Seller: Determines the price according to the formula [1] based on the simulation result, then announces it. Since for the limitation of the underwater communication the announcement should be the person-to person fashion, and some AUV may not get the message.

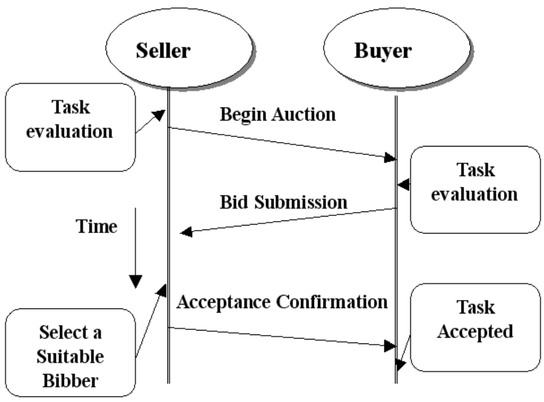

Figure 2. A Successful Auction

iii) Buyer: Evaluates the task proposed by the seller in simulation mode to get the local cost and determine the buying price according to formula [2].

iv) Buyer: Makes its own decision according to the formula [3] based on the simulation result. If "YES", the buyer submits its bid to the seller.

v) Seller: Wait for enough buyers or timeout, then chooses a proper buyer, modify the final price of the task and send confirmation message. The optimition resides in the selection of a suitable bidder, and the task will be transported to the place where fewer costs are required.

vi) Buyer: Wait for acceptance confirmation, if the bid is accepted, it adds the task to the committed task queue for future execution or re-sell.

A successful negotiation process can be illustrated by figure [2]. Along with the changing situation, the buyer can also re-sell the task to make more profit or avoid the unexecuted tasks. This iteration will make the whole task allocation dynamically adapted to the changed environment and the team's task execution state. Tasks are injected into the system by sending tasks messages to anyone of the team, who will then delivery the tasks to the others based on the auction mechanism.

3) Communication. The address-based communication method is deployed in our $MAUVS-CS$ system. The broadcast model may be more effective, but in the fact the acoustic links is a directed communication method. So we believe that the address-based approach could be easier to realize when real physical system concerned. The form of the communication language are the same both for AUV-to-AUV and Operator-to-AUV; a message would be like this:

$$Task: Source,\ Dest,\ TradeMode,\ TaskID,\ TaskType,\ Content,\ \Pr ice.$$

The language supports for both the heterogeneous and the homogenous task cooperation at the meta-level control.

The Simulation Tests

For the limitations of hardware, we validate the cooperative controllers mainly in the simulation environment, $MAUVS-SE$, recently developed for multiple vehicle research purpose.

1) The Simulator, $MAUVS-SE$. This simulator is a full-function AUV real-time simulation environment including most necessary simulation modules such as the vehicle dynamics simulation, the 3D virtual world, the sonar simulation, and the acoustic links simulation. It is a MAS-like distributed parallel-processing system, aiming at provide asynchronous real-time

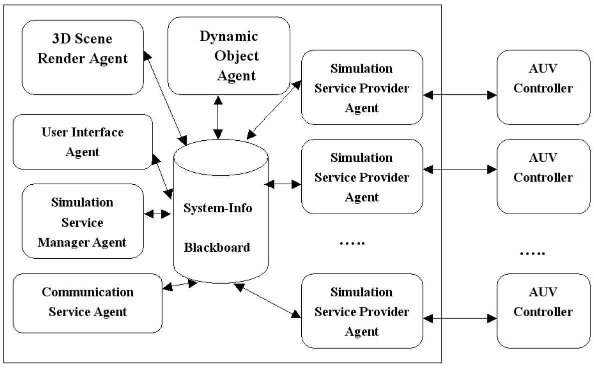

Figure 3. The $MAUVS-SE$ Simulator

simulation services simultaneously for multiple AUV controllers.

2) Multi-AUV minesweeping mission. The multi-AUV minesweeping mission can be achieved by deferent strategy []. Here we adopt the separately searching method, which is suitable for the complicated environment especially in the sallow water area. The mission has a team of four AUVs to reconnoiter a special area of minefields, which is divided into several sub-task areas beforehand. Thus, the team is required to search all the specified area and located mines successfully while minimizing overall costs. The simulation results are described by figure [4].

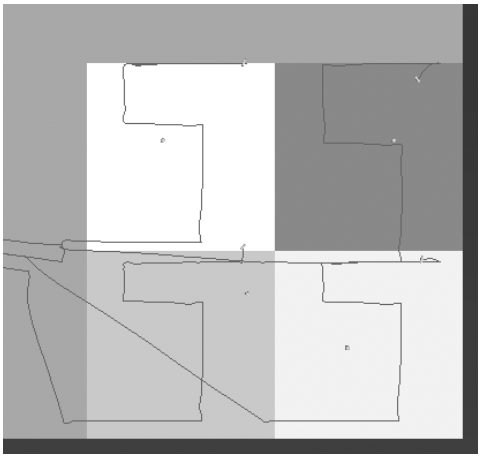

Figure 4. The Multi-AUV Minesweeping

3) MTSP-like task allocation. Many loosely coupled tasks are the kinds of the MTSP (Multiple-TSP) tasks; the minefields reconnaissance mentioned above is such a typical problem. Another example is the application of AUVs in the AOSN system. The observation stations are physically distributed in a large area and periodically visited by AUVs for data collection. SAMON [6] is such a control system, which is a layered hierarchical system based on fixed roles assignment. While we prefer to the more flexible dynamic distributed system, which is based on the negotiation between AUVs. The simulation involves 3 AUVs and 7 cities. The tasks are injected into the AUV system by sending messages to any AUV in the team; auctions occurs when other AUVs want to get tasks for more profits. Detailed discussion can be referred above. The simulation results are described by figure [5].

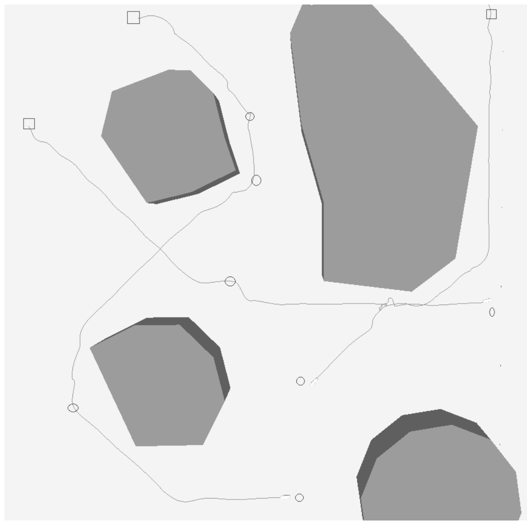

Figure 5. The MTSP-Like Task Allocation

Conclusion and Future Works

In this paper we propose a new multiple underwater vehicle cooperation mechanism, the “Market” approach. The initially implemented multi-AUV control system is a truly distributed control system for there is no central controller, which makes the AUV team more robust. Two simulation tests have successfully demonstrated the advantages of the market mechanism motioned above on our new simulation environment MAUVS-SE.

Till now, we have discussed the framework of the “Market” approach; future’s works should include the detailed discussion of the price and the iteration. On the other hand, the self-organization of the system should be also considered because the local optimum involving a certain number of AUVs can have active effect to the global optimum of the large-scale group. A lake test involved two AUVs are to carry out soon, which will give a simple but impressive demonstration of the multi-AUV system application.

Reference:

[1] R. Davis and R. G. Smith, "Negotiation as a metaphor for distributed problem solving," Artif. Intell., vol. 20, pp. 63–109, 1983.

[2] T. Sandholm, "An implementation of the contract net protocol based on marginal cost calculations," in Proc. Nat. Conf. Artificial Intelligence (AAAI), Washington, DC, 1993, pp. 256–262.

[3] M. B. Dias and A. Stentz, "A free market architecture for distributed control of a multirobot system," in Proc. 6th Int. Conf. Intelligent Autonomous Systems, Venice, Italy, July 2000, pp. 115–122.

[4] Mark S. Miller, K. Eric Drexler. Markets and computation: Agoric open systems. In B.A.Huberman, editor, The Ecologu of Computation, pp.133-176. North-Holland, Amsterdam, 1988.

[5] R.M. Turner and E.H. Turner. A two-level, protocol-based approach to controlling autonomous oceanographic sampling networks. In the IEEE Journal of Oceanic Engineering special issue on autonomous oceanographic sampling networks, vol. 26, no. 4, pp. 654-666, October, 2001.

[6] Bellingham, James G. New Oceanographic Uses of Autonomous Underwater Vehicles. Marine Technology Society Journal, 31(3):34-47. Fall 1997.

[7] Ratnesh Kumar, James A.Stover, "A Behavior-Based Intelligent Control Architecture with Application to Coordiantion of Multiple Underwater Vehicles", IEEE TRANSACTIONS.MAN,AND CYBERNETICS-PART 1:SYSTEM AND HUMANS.VOL.30NO.6.NOVEMBER 2000.

[8] Gerkey, B.P.; Mataric, M.J.;Sold!: auction methods for multirobot coordination Robotics and Automation, IEEE Transactions on , Volume: 18 Issue: 5 , Oct 2002 Page(s): 758 -768