Strategies for Distributed Underwater Survey

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Abstract. Underwater survey by a team of autonomous robots brings couple of problems caused mainly by the communication restrictions due to the nature of environment. Communication range and bandwidth are very limited and individual robots can become temporarily inaccessible. To allow robots' efficient operation in such environment architecture of control part of autonomous robot and new algorithms for decentralized coordination within a group of such robots were developed. Besides these this paper describes experiments addressing different area search and video stream transmission path planning strategies.

1 Introduction

We decided to simulate the underwater survey problem [1] using a multi-agent system as it represents a natural choice to model distributed systems consisting of autonomous, self-interested entities like the teams of autonomous robots.

In such a type of scenario no dedicated central planning entity can be used: (i) because of the limited communication accessibility, robots can easy get out of the central entity's communication range and (ii) in case of malfunction of this entity robots without their own planning capabilities will fail to coordinate their activities. Unlike the other works where authors investigate mainly the team action planning activities e.g. [2,3], in this project we focused on communication and knowledge synchronization in environment with partial communication inaccessibility and transmission path establishment algorithms.

2 Scenario Implementation

In our scenario goal of the group of autonomous robots (unmanned underwater vehicles - UUVs) is to search a given coast area, detect and remove all mines located there. To allow an object analysis video transmission path must be established between the base (operated by human crew) and robot who found the suspicions object. Due to the specific scenario features (environment simulation, communication inaccessibility) we decided to use $\mathcal{A}$**-globe** multi-agent platform [4,5] as a simulation environment.

Two types of communication accessibility are simulated – **high bandwidth** (very restrained, necessary for video transmissions) and **signaling** (higher than

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video but remains limited, used for coordination messages and position information). Each robot consists of following components:

- **Robot Pod** simulator, computes robot moves and updates its position with environment simulation server.
- **Mine Detector** simulator, provides the decision-making components with information about suspicions objects found.
- **Video** data acquisition and transmission element. This subsystem creates the video feed of suspicions object to the remote operator.
- **Robot Coordinator** implements search algorithm, transmission coalition establishment and negotiation.

3 Distributing the Coordination Process

The process of agents' coordination can be done centrally by a dedicated central coordination agent. This agent may however become a bottleneck in situations when several robots request new tasks at the same time or are out of the entity's communication range.

Coordination process can also be distributed among agents in several levels: (i) there is no central coordination agent, each robot can become a coordinator for a single feed planning process, (ii) coordination process is in parts distributed among the agents, but the participating robots are preselected, and (iii) coordination process is distributed completely among the agents. There is no central plan, robots negotiate in peer-to-peer manner.

The level-1 and level-2 distribution is desired for the increased efficiency, flexibility and survivability of the coordination process. The level-3 distribution of coordination makes sense only in the situations when it is impossible to bring all the planning information to the coordinator.

3.1 Transmission Collaborators Search Strategies

To transmit the video stream of suspicions object to human operator, relaying via several collaborators is usually required. If sufficient number of collaborators is not available, robot can search for other robots to help him to build the feed:

Central Planning Algorithm: Using this algorithm robots do not form the video feed immediately after the object is found, but store the object's position in memory and continue in search. Video stream of all objects is transmitted on their way back to base, after the whole area is searched.

Relayed Collaborator Search Algorithm: Robot who finds suspicions object becomes a coordinator of the transmission planning and asks other robots within its communication range for their actual status and position. Robots relay this information to their neighbors, etc. If sufficient number of collaborators is found, coordinator uses this information to plan the feed.

Elastic Collaborator Search Algorithm: In some cases robots can not find enough collaborators even when using the relayed communication. This algorithm allows robot to leave the suspicions object and look for the missing collaborators.

3.2 Transmission Path Planning Algorithms

We have developed three different algorithms to build the ad-hoc data transmission feed. The most straightforward are the approaches relying on a single agent mastering the planning process. Upon finding the suspicions object, it requests other visible robots to move to specific positions so that a high-bandwidth transmission link between the object and the base is established.

When we optimize the communication quality, minimal possible number of robots is used. On the other hand, when we try to minimize the impact on relay robots' own plans, relays are spread in the area between the transmission origin and target, in the proximity of their original areas. In the third approach, the control over the feed planning is not centralized, but rather passed along the communication link relays when the connection is constructed.

Direct Line Transmission Path Planner (DLTP): It achieves the level-1 coordination process distribution. Robot who finds the suspicions object has to select the best subset from all available robots. Positions of participants are placed on the join of base and object position in periodic distances. Length of this distance is equal to the video transmission range.

Minimal Time-To-Transmit Planner (M3TP): Using this planner more than the minimal required number of robots can participate in video transmission. Optimization criterion is to minimize the time the intermediate robots spend on transmission. Optimal placement of robots can form a general curve not only a line. It is computationally infeasible to search a whole state space, new algorithm based on modified Dijkstra's graph search algorithm was thus developed.

Decentralized Planner (DP): Robot that found a suspicions object only verifies accessibility of minimal required number of robots. If such a number is available, subset of all mutually accessible robots is selected to build a transmission path. All these robots are then informed about their order in the transmission path. Each of them then starts to move to the position where both the previous and next robot in the feed are accessible for video transmission and informs them about its new positions during the movement.

4 Experiments

A set of experiments was carried out, mainly to study the features of transmission collaborators search strategies. We were using two different environment setups, where the mines were placed: (i) in pattern and (ii) randomly with uniform distribution. As shown in fig. 1 use of the central planning algorithm ensures that all video streams will be transmitted online. For short transmission times this algorithm performs best also for the overall area search duration. Relayed search algorithm can be with advantages used in environments where each new detected object can bring additional tasks. This algorithm can be also interrupted at any moment and at least part of the area can be marked as searched. Use of elastic search algorithm increases the number of online transmissions compared to relayed search algorithm, but for the price of longer transmission times.

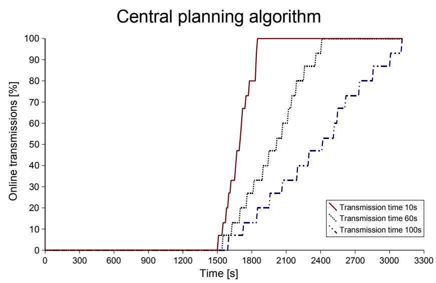

Fig. 1. Central planning algorithm - dependency of the number of online transmissions on length of transmission time

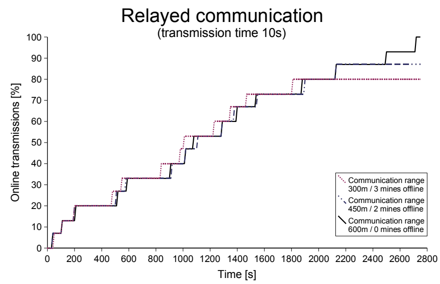

Fig. 2. Relayed communication - influence of communication range on the number of online transmissions

5 Conclusion and Future Work

Within this project we have developed a specific simulation environment using the $\mathcal{A}$-**globe** multi-agent platform. Main reason to develop such environment was to enable a software simulation of real-life hardware robots where scalability experiments and efficient development and verification of embedded decision making algorithms can be carried out. The experiments conducted in the simulation environment with various environment settings (movement speed, number of mines, length of the transmission time) have proved that each collaborator search strategy is suitable for different area of tasks (hydrographic or geophysical surveys, minesweeping, etc.). Based on the actual task and environment features, operator can decide which algorithm will be used.

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