Riassunto papers

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1 "Collaborative Multi-Robot Exploration" - Burgard

In this paper is considered the problem of exploring an unknown environment by a team of robot. The main focus is on the coordination of a team of multiple robots by the definition of target points for the exploration.

Mainly two previous approaches concerning multiple robots exploration are presented. First one consists in separating the environment into stripes and then explore them by moving just one robot and keeping the other stationary. This reduces odometry error but robots are forced to stay close to each other. Second one considers the use of a common map built as the exploration goes on and as a robot discovers an opening to an unexplored area, which can't reach due to its size, it chooses another robot to achieve this task. The selection is performed taking into account the number of areas to explore, size of the robot and the distance of the robot and the target location. This approach moves robots to the closest unexplored frontier but neither provide a coordination mechanism to avoid the selection of the same frontier by multiple robots nor it uses an accurate distance measure, using straight line distance rather than a computation on the current map.

The approach presented in this paper uses occupancy grid maps to represent the environment and assumes robots to know their relative position during the whole exploration process. This assumption is useful to allow a simple computation of the integrated occupancy grid map. The selection of target points to explore is based on two concepts: the cost of reaching it and the utility it provides. Cost for traversing a cell is proportional to the occupancy value of that cell and through that definition, the minimum cost path between two cells can be computed. The utility of a target point is calculated as the expected visible area from that point. To find out this value, it exploits an heuristic based on the observation that a robot exploring a big open terrain can cover much larger areas than a robot exploring a narrow part of the environment. This is achieved by counting the number of times $h(d_i)$ the distance d_i was measured by any of the robots. The value of $h(d_i)$ is then used to compute the probability that the robot's sensors covers objects at distance d. A great advantage of the algorithm introduced is that two robots never choose the same target point because once a robot is assigned to it, utility of that point is decreased accordingly.

The provided experimental results only deal with an office-like environment and show that the coordination always provides better performances. Moreover, two coordinated robots have performances similar to three uncoordinated robots and the improvement introduced by the coordination is almost the same both with two and three robots.

2 "Coordinated Multi-Robot Exploration" - Burgard

As in the previous paper, the focus of this one is on the coordination of a team of multiple robots by the definition of target points for the exploration, but it also takes into account limited communication among them.

The algorithm used for the assignment of the target points is almost the same as above. Few differences are introduced in the reduction of the utility of a frontier cell after a robot is assigned to an adjacent one and in determining the pair robot-frontier cell. In fact, in the previous case, cost and utility had the same weight, now the relative importance of utility versus cost is modified through a positive factor β. Moreover, experiments performed, showed that if $\beta \in [0.01, 50]$ the exploration time is almost constant. While if $\beta > 50$ the impact of the coordination decreases, thus the exploration time increases. While if it is near 0, robots ignore distance to be traveled, increasing again the exploration time.

Limited communication range affects highly the algorithm explained before, but it is easily modified to deal with this problem by applying it to every sub-team of robots which are able to communicate with each other. Another issue derived from the limited communication consists in when new assignments have to be computed. In fact, in the case of perfect communication, they can be calculated whenever a robot reaches its target. In the other case, this approach can't be pursued. Therefore, what is done is to store in each robot the latest target locations assigned to other robots; in this way, robots avoid going to places already explored by other robots.

It is meaningful to point out that to achieve coordination, the team must be able to communicate the maps of the individual robots during exploration. Main idea is to split the team of robots into clusters, and messages sent by a robot are forwarded to all team-mates in the corresponding cluster. If every cluster maintaines a map built from all observations made by robots of that team, if connection problems are encountered, it may happen that the map is updated twice, which is not admissible. An efficient way to overcome this problem is to have each robot storing a log of sensors measurements perceived by this robot and only trasmits those measurements that have not been transmitted to the corresponding robot so far. Additionally, a data structure containing the time stamp of the last transmission to each robot is stored. In this way, as a measurement has been sent to all other robots can be discarded.

The experiments are performed on three different maps: an unstructured one, an office-like and a corridor environment. In all the three cases, the coordinated algorithm outscales the uncoordinated one. This is due to the better distribution of the robots in the environment, allowing to speed up the exploration.

3 Coordination for Multi-Robot Exploration and Mapping - Simmons

This paper main topics are the definition of a mechanism for coordinated mapping and another for coordinated exploration.

The coordinated mapping approach works with (reasonably) static world and assumes that in the beginning, robots know their relative position. It decomposes the mapping problem in a modular way, being composed of a local map stored on each robot and a global map kept by a central mapper. As a robot receives its own odometry and sensor measurements, it computes a maximum likelihood extimation of its position, a maximum likelihood extimation for the map and a posterior density of its "true" location. This update takes into account both noise in motion and in perception, moreover it converges fast. For what concerns the central mapper, its main role is to integrate informations coming from the robots in real-time. This information are sent after having collected a certain number of them and the central mapper combines them by minimizing the error between the scans of the different robots.

The coordinated exploration approach makes each robot construct a "bid", on the basis of the expected utility for it to travel to a frontier cell and the expected information gain there. Cost is computed as the optimal path from the robot's current position. The information gain is estimated by assuming that the robot has a nominal sensor range and then counting the unexplored cells which fall within the radius of the frontier cell. Also the maximum and minimum extent of the information gain region are stored because they are used to forme a rectangle that approximates this region. It is useful to find potential overlaps in coverage. This approach makes robot move enough far to optimize exploration but if there is an obstacle separating them like a wall, they move near it but in the different rooms. The algorithm used to assign tasks to robots is a greedy one, assigning the first task to the bid with highest net utility. After that, other bids are discounted by estimating the percentage of overlap with the already assigned task and then it assigns new task with same criteria as before. This process goes on up to the end of the tasks or the available robots. Moreover, it is introduced the concept of hysteresis, which is useful to handle the high variation that might be measured in the information gain metric.

The experiments are performed on real robots in an hospital building composed of corridors and offices. Main behaviours to point out are that three robots start in a narrow corridor, then one will stand still and the other two will go to the frontiers and that if one robot goes near a task assigned to another one, then the task is dynamically swapped to the nearer robot.

Other reported experiments run in simulator have been performed in five different environments, a single-corridor office, a two parallel corridors office, an obstacle-free environment and two random unstructured environments. In all the cases, increasing the number of robots improves results but the amount of improvement depends on the characteristics of the environment. In fact, in the first two environments, moving from two to three robots doesn't have the same impact as switching from one robot to two because the third robot is almost useless. In the obstacle-free environment, a single robot exploration has an high rate of failure, which is highly mitigated by switching to two robots and it's even better with three. Also the accuracy of the map increases with the number of robots. For what concerns the unstructured environments, the presence of obstacles helps in spreading the robots around, so this makes the improvement of using three robots rather than two way higher than moving from one to two.