Semi-autonomous Coordinated Exploration in Rescue Scenarios

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Abstract. In this paper we study different coordination strategies for a group of robots involved in a search and rescue task. The system integrates all the necessary components to realise the basic behaviours of robotic platforms. Coordination is based on iterative dynamic task assignment. Tasks are interesting points to reach, and the coordination algorithm finds at each time step the optimal assignment of robots to tasks. We realised both a completely autonomous exploration strategy and a strategy that involves a human operator. The human operator is able to control the robots at different levels: giving priority points for exploration to the team of robots, giving navigation goal points to team of robots, and directly tele-operating a single robot. For building a consistent global map, we implemented a centralised coordinated SLAM approach that integrates readings from all robots. The system has been tested both in the UsarSim simulation environment and on robotic platforms.

1 Introduction

The use of mobile robotic platforms for search and rescue missions is envisioned as a critical issue for society. Mobile robotic platforms can consistently help human operator in dangerous or complex tasks, providing important information for areas that cannot be directly reached.

To consistently help the human operator during rescue missions, robotic platforms should exhibit a certain level of autonomy in their behaviours. break Semi-autonomous robots can process acquired data and build a high-level representation of the surrounding environment. Moreover, robots can act in the environment (e.g. navigate) with only a limited interaction with the human operator. In this way, the human operator can easily control multiple robots providing high level commands (e.g. "explore this area", "reach this point", etc.). Moreover, in case of temporary network breakdown, the mobile bases can continue the execution of the ongoing task and return to a predefined base position.

In this paper we focus our attention on coordinated autonomous exploration by a team of mobile robots in an unstructured environment. A team of coordinated mobile robots can explore an environment faster than a single robot, moreover, using several robots the system can be robust to platform failures.

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Autonomous exploration has been deeply investigated in mobile robot literature [1,2]. The main problem of autonomous exploration is to choose a sequence of targets reachable by a robot, so to explore all the environment optimising an objective function. As for multi-robot exploration, the main problem is to coordinate the robot activities so to avoid conflicts in the exploration process. In particular, the goal is to spread the robots in the environment collecting all available information [3].

This paper makes two main contributions. First, we present a novel semi-autonomous coordinated exploration system for a team of mobile robots involved in a rescue scenario. The main novelty of the approach is to devise a semi-autonomous strategy that allows an operator to give high level advices to the entire team of cooperating robots. The team is responsible to coordinate and decide who should fulfil the user requirements. Second, we present an evaluation methodology for exploration strategies. Our methodology is based on an extensive evaluation of several experiments on a high fidelity simulated environment (i.e., the UsarSim environment), and then validation of the approach with real robotic platforms. We are able in this way to compare and analyse different coordination strategies for the exploration. In particular, we compared the totally autonomous coordination exploration with the semi-autonomous approach.

The idea of providing high level advices to a team of agents has been addressed in the DEFACTO system by Schurr et al. [4]. The DEFACTO system is a system built on top of the RoboCup rescue simulator used to train incident commander for intervention in large scale urban emergencies. Coordination is provided using Machinetta, a general framework for teamwork in multi-agent system [5]. With respect to the DEFACTO system our work is more focused toward specific robotic problems (e.g., cooperative SLAM, motion planning, etc.), moreover, we specifically focus on a single aspect of the coordination problem (i.e., task assignment) to have a full evaluation of this issue.

The work by Wang et al. [6] addresses the cooperation of rescue robots supervised by human operator. Also Wang et al. use the Machinetta framework for ensuring teamwork among robotic platforms. The work evaluates the cooperation between robots and human operator via a series of experiments involving different users. As before, our approach is more focused toward the specific evaluation of task assignment, and the use of real robotic platform.

2 Coordinated Exploration Strategies

The problem of coordinating the exploration of a set of robots can be conveniently formalised as a task assignment problem [3]. Task Assignment is a very well known approach to address coordination of autonomous robot activities. The classical task assignment formulation is to assign a utility value to the task to be executed. The utility function is dependent on the task and on the status of the agent that is allocated to that task. The goal of the task assignment is to maximise the sum of the utility of the allocation of agents to tasks.

We realised two coordination strategies: one is distributed and robots are not controlled by the human operator, while the second one is supervised and centralised.

2.1 Distributed Autonomous Coordination

In this strategy robots are completely autonomous.

A task assignment strategy is employed to allocate robots to different tasks. A task in our environment is a goal target to be reached by the robot Our approach extends the method proposed in [7]. In particular, with respect to [7], in our approach the number of tasks to be executed is not fixed, and there is no total priority order for the tasks.

Our approach works as follow: each robot maintains a structure containing the tasks known to all the agents. Each robot locally computes the current target points to reach, and verifies that they are not within the current tasks already known to the system. To compare the tasks a simple nearest neighbour technique is used. Each robot sends in broadcast the new tasks to all team mates, computes its utility function for all the tasks present in the system and broadcasts the function values to all other team mates. Each robot computes autonomously the best allocation of robots to targets and then execute the best task according to the chosen allocation. The best allocation is computed considering all possible assignment of robots to tasks, and choosing the one that maximises the sum of utility functions.

The algorithm used to compute the utility function is shared among all robots and is based on specific parameters that influence the task execution (e.g. distance to travel). Since all robots use the same algorithm with the same data, eventually they will all converge to the same solution, even though temporary oscillations of the algorithm might happen due to noise in the robot local estimate of the utility functions. Following the approach in [7] we use hysteresis on the allocated tasks to avoid this problem. Whenever a task is accomplished by a robot, a message is sent broadcast to all other team mates to update the task set.

2.2 Centralised Semi-autonomous Coordination

The supervised centralised coordination strategy relies on a base station common to all the robots, where all information are channeled. A human operator is in charge of supervising the robot team by monitoring the mission execution and by controlling the robots at different levels.

The central station is in charge of combining the single robot readings and provide a global comprehensible picture to the human operator. In particular, the base station combines the laser readings of different robots to build a consistent joint map. To merge the laser reading a Rao-Blackwellized particle filter method is employed. The method extends the work presented in [8], considering the joint states of all the robots as the variable to be estimated.

To ensure an effective control by the human operator a multi-robot graphic user interface has been developed within the RDK framework [9] (see figure 1). The multi-robot console allows the human operator to see the global map built by the robot team, to see interesting states of the robots, and to control them.

Robots can be controlled using one of the following operational modes: Autonomy, Navigation, Operated. When robots are in autonomy mode they will execute the exploration strategy described in [10]. Moreover, they coordinate using the algorithm described in section 2.1. When the Navigation mode is selected, the robot waits for a goal point to be provided by the operator. When a goal point is provided, the robot will autonomously navigate towards the specified point using the approach described in [11]. Finally, when the Operated mode is selected the robot will not try to act proactively, waiting for low level commands from the operator (e.g., joystick commands). Both the Navigation and the Autonomous modes accept target points by the operator. When a target point is inserted, it is sent to all the robots. Each robot will then perform the task assignment strategy specified in the previous section, treating the goal point sent by the human operator as a high priority task. In this way, the human operator does not have to decide which robot is in charge of exploring a particular area but can just signal interesting parts of the map to the robots and monitor their execution. If a robot is in the Navigation mode, when it reaches the goal point provided by the human operator, it will stop waiting for another goal point. If a robot is in Autonomy mode, after reaching a human goal-target, it will keep executing the frontier base exploration from the current position.

Notice that while the global map is estimated by a centralised process each robot maintains a local map built autonomously. Therefore if a communication breakdown interrupts the link between one robot and the central station, the robot is still able to perform its tasks reasoning on its local map. The global map is used only by the human operator to monitor the mission execution and to control the robots.

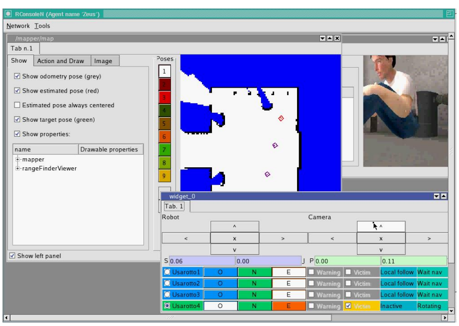

Fig. 1. The multi robot control console

Fig. 2. Map used for the experiments

3 Experiments and Results

We conducted extensive experiments using the UsarSim [12] simulation environment, and then validated our approach on real robotic platforms.

3.1 Experiments in UsarSim

Our evaluation methodology is to perform experiments on a benchmark scenario and extract significant metrics for each mission, varying some interesting parameters.

To acquire quantitative data we used the UsarSim simulation environment. UsarSim is a 3D high fidelity simulation of Urban Search And Rescue (USAR) robots and environments. UsarSim is a valid tool for the study of basic robotic capabilities in 3D environment. It offers several 3D models of robotic platforms (P2DX, P2AT, Zerg, ATRVJ, etc. etc.) and sensors (Laser Range Finder, IMU, Color Camera, etc).

A sensible metric to evaluate the performance of an exploration mission is the time needed to complete the exploration.

Figure 2 reports a picture of the map used in the experiments. An important parameter to consider into the experiments is the dimension of the map.

Our reference map is composed by a central corridor (16 meters long and 3 meters wide) and a series of rooms. We divide this map into three different maps: a small size map (one third of the corridor plus the two small adjacent rooms), a medium size map (two third of the corridor and two additional rooms) and a large size map (the whole environment). Notice that, while the map used for experiments has a clear structure, the representation that robots have of the map makes no assumption of such a structure. In fact, experiments with real robots have been performed in a much less structured environment (see next section). The only assumption that must holds for our exploration method to work correctly is to have planar environment. This is due to the SLAM algorithm which is designed for such kinds of environments.

We used two wheeled robots: P2AT and P2DX, both of them equipped with a Laser Range Finder.

To have a baseline value to compare between the different coordinated strategies, we measured the time needed by a single autonomous P2AT[1] and then compute the percentage of time used by the other strategies with respect to this value.

The different strategies we compared are the following: i) Two autonomous non-coordinated platforms *AutNotCoord*; ii) Two autonomous coordinated platforms *AutCoord*; iii) Two supervised coordinated platforms *SupCoord*

Table 1 reports the obtained results. We performed several experiments for each strategy. Since each experiment involves the exploration of a consistent part of a building, the time of completion for each mission depends on several parameters. Therefore, the collected results have a consistent variance and cannot be well represented with a simple average. To take into account this issue, we report the interval between the minimum and maximum values obtained.

[1] The exploration time of a single autonomous P2DX is very similar to the P2AT.

Table 1. Comparison among the different coordination strategies over different environments

	Small	**Medium**	**Large**
AutNotCoord	80%	80%-85%	80%-90%
AutCoord	75%	70%-75%	65%-75%
SupCoord	65%	55%-60%	45%-55%

The results show several interesting points. First of all, the autonomous coordinated system has better performance with respect to the autonomous not coordinated one. In particular, coordination plays a crucial role for larger spaces. This is because the larger the environment the more important is to avoid that the same portion of space is covered by more than one robot. Second, the supervised coordinated strategy outperforms the autonomous coordinated strategy. This can be explained considering that the human operator has more information than the single robots. The autonomous coordinated strategy we employ, exchanges only tasks to be accomplished by the robots, trying to optimise the task allocation process. In particular, for our exploration scenario the robots exchange only the current goal points of the exploration strategy, and they do not exchange maps or map patches. When the supervised coordination strategy is used, the human operator has a more complete knowledge of the environment (given by the global merged map) and can make more informed decisions. However, notice that the supervised strategy requires a high amount of information to be transfered from the robots to the central base station. Moreover, the central base station should be always reachable through direct communication with every robots.

Since the coordination algorithms evaluated and the exploration strategy used do not make any assumption on the particular structure of the map, we believe that obtained results should be valid for other types of environments and maps. Moreover, since the computation of utility function for the Task Assignment is demanded to each single robotic agent, the coordination algorithm can be extended to take into account robots with heterogeneous sensing and mobility capabilities.

However, a deeper investigation is needed, in order to clearly understand how the obtained results relate to such situations.

3.2 Experiments with Real Robots

We validated our approach with two mobile platforms: a P2DX equipped with an Hokuyo Laser Range finder, and a P2AT equipped with a SICK Laser Range Finder. The experiments have been conducted in the arena set up in our lab.

Figure 3 shows the maps created by the robots during their mission. The environment to explore is 7×6 square meters, and the two robots completed the exploration in 10 minutes approximately. From left to right it is possible to see the initial situation, a snapshot during the exploration process and the final map. The P2DX is represented with a circle and the P2AT is represented with a square. In the maps it is possible to see the current tasks the robots are allocated to (crosses in the map). Robots performed a coordinated supervised exploration. Giving high level advices the operator was able to efficiently control the system, nicely spreading the two robots.

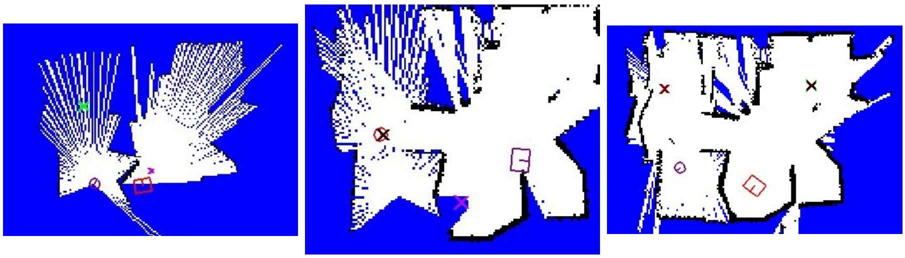

Fig. 3. Cooperative exploration sequence

Figure 4 shows the two maps of the single robot. These are the maps the two robots maintain locally. As it is possible to see the overlapping among the two maps is minimal, as it is desirable in a multi-robot exploration task. On the other hand, a bigger overlap between the two maps would have been beneficial for the cooperative SLAM process, and would have produced a better quality global map. In this work, we focused on minimising the exploration time rather than having a better quality map.

Fig. 4. Maps of each single robots: P2DX left and P2AT right

4 Conclusions and Future Work

In this work we presented an evaluation of different coordination strategies in a rescue scenario. We designed, realised and compared a totally autonomous coordination strategy and a supervised coordination strategy. Quantitative experiments have been performed using the UsarSim environment, and the system has been validated also on real robotic platforms.

An interesting future topic will be to extend our current approach to consider possible lack of communication link between robotic platforms and the human operator. This is a very important issue to consider and has a significant impact on the overall coordination strategy used in our approach.

References

1. Stachniss, C., Grisetti, G., Burgard, W.: Information gain-based exploration using rao-blackwellized particle filters. In: Proceedings of Robotics: Science and Systems (RSS), Cambridge, MA, USA (2005)
2. Yamauchi, B.: A frontier based approach for autonomous exploration. In: IEEE Int. Symp. on Computational Intelligence in Robotics and Automation (1997)
3. Zlot, R., Stenz, A., Dias, M.B., Thayer, S.: Multi robot exploration controlled by a market economy. In: Proc. of the Int. Conf. on Robotics and Automation (ICRA), pp. 3016–3023 (2002)
4. Schurr, N., Patil, P., Pighin, F., Tambe, M.: Using multiagent teams to improve the training of incident commanders. In: Proceedings of the Industry Track of the Fifth International Joint Conference on Autonomous Agents and Multiagent Systems (2006)
5. Scerri, P., Pynadath, D.V., Johnson, L.: A prototype infrastructure for distributed robot-agent-person teams. In: Proceedings of AAMAS (2003)
6. Wang, J., Lewis, M., Scerri, P.: Cooperating robots for search and rescue. In: Agent Technology for Disaster Management Workshop at AAMAS 2006 (2006)
7. Iocchi, L., Nardi, D., Piaggio, M., Sgorbissa, A.: Distributed coordination in heterogeneous multi-robot systems. Autonomous Robots 15(2), 155–168 (2003)
8. Grisetti, G., Stachniss, C., Burgard, W.: Improving grid-based SLAM with Rao-Blackwellized particle filters by adaptive proposals and selective resampling. In: Proceedings of the IEEE International Conference on Robotics & Automation (ICRA) (2005)
9. Farinelli, A., Grisetti, G., Iocchi, L.: Design and implementation of modular software for programming mobile robots. International Journal of Advanced Robotic Systems 3(1), 37–42 (2006)
10. Calisi, D., Farinelli, A., Iocchi, L., Nardi, D., Pucci, F.: Multi-objective autonomous exploration in a rescue environment. In: Proc. of IEEE Int. Workshop on Safety, Security and Rescue Robotics (SSRR), Gaithersburg, MD, USA (2006)
11. Calisi, D., Farinelli, A., Iocchi, L., Nardi, D.: Autonomous navigation and exploration in a rescue environment. In: Proc. of IEEE Int. Workshop on Safety, Security and Rescue Robotics (SSRR), Kobe, Japan, pp. 54–59 (2005) ISBN: 0-7803-8946-8
12. Carpin, S., Lewis, M., Wang, J., Balakirsky, S., Scrapper, C.: Bridging the gap between simulation and reality in urban search and rescue. In: Lakemeyer, G., Sklar, E., Sorrenti, D.G., Takahashi, T. (eds.) RoboCup 2006: Robot Soccer World Cup X. LNCS (LNAI), vol. 4434. Springer, Heidelberg (2007)