RoboCup Rescue 2013
LTI Agent Rescue Team Description

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Abstract. In this paper, we describe the strategy implemented by the LTI Agent Rescue team for the RoboCup Rescue Agent Simulation 2013 competition. We mainly focus in some aspects identified as the bottleneck of the team's performance in the 2011 competition: the map exploration and the coordination strategy. In order to improve the map exploration, we use a map partitioning technique to allocate Police Forces to specific regions of the map, whilst changing the task allocation approach from a hybrid to a distributed one in order to improve the coordination strategy. Moreover, we implement some techniques to avoid communication channel overload, such as data compression and interleaved communication.

1 Introduction

Natural disasters are a source of concern for virtually every country in the world as they usually are difficult to predict and cause huge human and material losses. Although some disasters may be predicted in considerable advance, most of them cannot, which leaves a short period of time for any preventive action. Thus, it requires the pre-existence of efficient policies to help handling and responding to such situations, which makes disaster management an important discipline.

According to Blanchard et al. [1], disaster management is comprised of four phases: mitigation, preparedness, response and recovery. In order to promote research on techniques focused on the response phase of disaster management, the RoboCup Rescue Agent Simulation League [5] was founded in 2000. The competition approaches the problem from a multiagent system perspective, in which teams of heterogeneous agents act on simulated post-earthquake scenarios. This kind of scenario imposes great challenges to the development of teams of agents since the environment is dynamic, information and communication are limited and unreliable, and the time to take a decision is limited.

The LTI Agent Rescue team is applying for its second participation on the competition. For RoboCup 2013, we focus on some aspects identified as the bottleneck of the team's performance on the 2011 RoboCup competition: the map exploration and the coordination strategy.

Previously, the map exploration was performed based on the random walking strategy, however it caused a concentration of agents in specific regions of the map leaving many parts of it unexplored, victims undetected and fires unnoticed. Besides, the channel communication characteristics were not explored since the team used a strategy that concentrated all gathered information and communication on the *center* agents.

Therefore, some changes and improvements have been made for the RoboCup 2013 competition. In order to mitigate the map exploration problem, we developed a method of map partitioning, used by the Police Forces to divide the map into sectors and reduce the patrolling area of each one of them (see Section 3). Regarding the coordination approach problem, we changed how the agents exchange information among themselves in order to allow them to communicate directly without requiring the *center* intermediation. Thus, it changed the task allocation from a hybrid to a completely distributed approach. Moreover, some techniques to avoid channel overload, such as the Adaptive Huffman encoding [4,7] and interleaved information exchange, were implemented (see Section 4).

The rest of the document is structured as follows. Section 2 describes the distributed strategy employed in the development of each kind of agent, as well as their specific behaviors. Next, the map partitioning technique developed to subdivide the map for Police Forces' surveillance is described with a preliminary performance evaluation in Section 3. In Section 4, we present the communication protocol used to enable the information exchange among the agents. Finally, the main conclusions are presented in Section 5.

2 Strategy

In RoboCup 2011 [6], LTI Agent Rescue team implemented a strategy that followed a hybrid task allocation approach to control and coordinate agents in the RoboCup Rescue Simulator (RCRS) platform. Such approach was inspired on the *Partial Global Planning* (PGP) approach [3] in which the agents exchange information in order to reach common conclusions about the problem to be solved. It is considered *partial* because agents have limited information of the environment available in order to take the best possible decision; on the other hand, it is *global* because the agents can exchange and obtain relevant missing information from each other when necessary.

The proposed hybrid approach intended to exploit the advantages of the *centralized* and *distributed* approaches, considering and handling the existence of both local and global information, making the *platoon* agents not completely dependent of the *center* agents, being even capable of functioning on an environment without communication. Despite being inspired on PGP approach, the proposed approach had four key differences to the PGP:

- The agents exchanged tasks instead of plans;

– There was no direct communication among *platoon* agents, which required the performance of such tasks by the *center* agents;
– The global information was stored in the *center* agents;
– The global information was only requested and used when the agent's had no local tasks to act upon.

Based on the experience obtained in RoboCup 2011, we have decided to adopt a new strategy for RoboCup 2013, in which the information storage and decision making are completely local, and the agents exchange obtained informations directly among themselves. The new strategy follows a distributed approach.

The main reason for such change is that, since the release of the new RCRS platform in 2010, the *platoon* agents can communicate through channels directly among themselves, canceling any imperative need of the *center* agents intermediation. In fact, using center-intermediation generates a delay of one cycle in the process of information exchange, worsening the situation instead of bringing any real advantage in the case of a distributed approach. Hence, the *center* agents play no role in this new strategy.

Moreover, using a distributed approach brings some advantages concerning the previous one, such as the nonexistence of a single point of failure and the elimination of possible bottlenecks. Besides, task allocation can still be performed even if the agents have little or no interaction with other agents, which is interesting for an environment like the RCRS, where the communication is subject to failure or not available at all.

The disadvantage of this approach is that the communication channel may be overloaded, for example, in the case when all the agents are connected to the same channel. Thus, in order to overcome this problem, a set of techniques such as interleaved information exchange, data compression, and transmission of only required data is applied and detailed in Section 4.

In order to implement the new strategy, each agent maintains two databases, one of *tasks* and another of *world information*. In our context, *world information* are data about the state of the environment's objects; *tasks* are world information upon which the agents may act, such as buildings on fire for Fire Brigades, blocked roads for Police Forces, and victims for Ambulance Teams. The task database will also indicate which agents are currently acting on each task.

Using these information, the following general agent behavior was designed:

1. The agent perceives the environment and receives messages from other agents;
2. The agent updates its world information database;
3. The agent generates a list of new identified tasks from the world information database;
4. The agent adds the new identified tasks to its tasks database and it also updates the list of the agents that are acting on each task;
5. The agent calculates the payoff of each task, taking into account the possibility of cooperation with other agents, and chooses the task with the highest payoff for act upon; if the agent has no task it can act upon, it moves randomly on the map looking for one;
6. The agent sends messages to other agents, comprised of:

– the world information whose state has changed;
– the task it has chosen to work on (if any).

Next, the specific behavior of each kind of agent is described.

2.1 Police Force

The Police Forces have an important role in the new strategy in order to overcome the map exploration issue faced in RoboCup 2011. Each one is given the task of performing the surveillance of a specific partition of the map. Other teams have already reported the use of mapping partitioning and we think that it will also help our strategy. Hence, our intents in partitioning the map are (i) to be able to better explore the map and identify faster possible tasks to act upon, and (ii) reduce the number of entities that each Police Force has to check, fastening the exploration process.

Besides, since Fire Brigades need to get to refuges to refill their water tank and Ambulance Teams need to have fast ways to reach the refuge when transporting civilians, clearing paths preventively to refuges is considered crucial in our strategy. Thus, in order to tackle this problem, we intend to use the Police Forces to perform preventive blockade removals. Therefore, when an Ambulance Team decides to rescue a civilian, it will communicate to all agents the location of its target. Then, the closest available Police Force will move to the target location and clean the path to the closest refuge, increasing the rescue successfulness. Since part of the Police Forces are used on the partitioning of the map, only the remaining agents are available to perform the preventive removal.

When operating without any request from Fire Brigade or Ambulance Team agent, the Police Force patrols its sector by visiting each road and building contained in it. During such activity, it may find new blockades or receive information from other agents about blockades, requiring it to choose one to act upon. To choose the right blockade to act, the *police* agent rules out the blockades that have other agent acting upon, since there is no advantage of more than one Police Force acting in the same blockade, and calculates the payoff of the remaining blockades. The payoff calculus (Eq. 1) takes into account the blockade repair cost and its distance, giving higher payoffs to blockades with small repair cost and that are closer to the agent.

$$\frac{1}{repairCost} * \frac{1}{\sqrt{distance}} \tag{1}$$

In order to clear more roads and cover a broader area, the Police Force clears the blockades up to the moment it can transpose it. In some cases, this does not require the complete clearing of the blockade, which saves time, improving the overall Police Force results.

2.2 Ambulance Team

The aim of the Ambulance Team is to rescue the highest number of civilians trapped inside buildings, called victims. In order to succeed in its goal, if the

Ambulance Team has no task assigned to act upon, it checks its tasks database and calculates the payoff value related to each task in it. The payoff calculus (Eq. 2) is the difference between the remaining life time of the victim and the expected time to rescue it, which is calculated based on the time to the Ambulance Team to arrive at the victim's location (victimTime), the time to load the victim (loadTime), the time to move from the victim to the nearest refuge location (refugeTime) and the time to unload the victim (unloadTime). The Ambulance Team chooses the task with the highest payoff value to act upon. Once a task is selected, the Ambulance Team moves to the victim's location, performs the rescue procedure, loads the victim, transports it to the closest unblocked refuge, and unloads the victim.

$$victimLifeTime - (victimTime + loadTime + refugeTime + unloadTime) \tag{2}$$

Usually, the Ambulance Team acts on the same task until the rescue is complete (victim in the refuge), however some situations may cause the Ambulance Team to give up on the victim and to look for other task to act upon, for instance if the Ambulance Team cannot reach the victim because all the possible paths are blocked or if the Ambulance Team identifies that the building in which the victim is trapped is on fire.

Moreover, we take into account the help request received from the trapped victims in order to improve the chance of knowing its position.

2.3 Fire Brigade

The Fire Brigade is the most difficult kind of agent to coordinate, because fires are highly dynamic in opposition to victims and blockades. They can appear randomly, spread during the course of the simulation and also reemerge after being extinguished.

The goal of the Fire Brigades is to find fires quickly and extinguish them, preventing it from spreading. Map exploration is important for that, thus Police Forces play an important role in the fire fighting activity. In case the Fire Brigades need to choose which burning building it will try to extinguish the fire first, it calculates the payoff (Eq. 3) of all the fire it knows and chooses the one with the highest payoff value.

$$\left(\frac{1}{buildingArea} * fieryness\right) + \frac{1}{\sqrt{distance}} + numberOfUnburningNeighbors \tag{3}$$

Using Eq. 3, it is expected to the Fire Brigade to choose the closest building with the smallest area, highest fire intensity and with the largest number of neighbors buildings that are not burning. Therefore, it should choose a small building that is closer to it and located at the border of a fire cluster.

3 Map Partitioning

The solution we propose to the problem of map exploration is the partitioning of the map into sectors, in which each Police Force is assigned to patrol one of the sectors. Police Forces are the obvious choice to explore the map because they have the ability to remove blockades, granting access to any place in the map. Additionally, the division of Police Forces in sectors ceases their encounters, reducing the number of idle agents.

The maps of the RCRS are graphs, such as the neighbors entities shown in the viewer of the simulator. Then, the goal is to obtain sectors in which their set of entities (buildings and roads) form a connected subgraph. Each entity will belong to an unique sector, therefore Police Forces that patrol different sectors do not visit the same location.

The algorithm divides the map into n sectors, where n is the number of Police Forces in the map. The number of sectors was defined arbitrarily and may be changed according to the map size and configurations.

The proposed map partitioning method divides the map into sectors comprised of:

- An index that identifies it;
- The two sets of X and Y coordinates that delimit its area;
- The set of entities it contains forming a single connected subgraph.

The pseudo-algorithm that performs the map partitioning is presented in Pseudo-Algorithm 1.

Pseudo-Algorithm 1 Map partitioning

Require: $n \Leftarrow numberOfSectors$

```
mapLength ⇐ Length of the map
mapHeight ⇐ Height of the map
term[2] = Factorization(n) {Factorize n into 2 numbers}
if mapLength > mapHeight then
   length = mapLength / term[2]
   height = mapHeight / term[1]
else
   length = mapLength / term[1]
   height = mapHeight / term[2]
end if
sectors ⇐ createSectors(length, height)
sectors ⇐ allocateEntities(sectors)
return sectors
```

First, it obtains the length ($mapLength$) and height ($mapHeight$) dimensions of the map in pixels. Then, it factorizes the number of sector (n) passed as parameter into two terms, where those terms are the closest factors of n, e.g. if

$n = 20$ then $term[1] = 4$ and $term[2] = 5$. If n is a prime number greater then 3, then the the first step would be getting the biggest non-prime number that is smaller than $n(n-1)$ and use this value in the factorization, then the remaining agent would be allocated randomly in one of the sectors. This case has not been covered by the Pseudo-Algorithm 1 for the sake of legibility.

After this, the largest dimension is divided by the largest term and the smallest dimension is divided by the smallest term. Based on those values, the sectors are created and their set of X and Y coordinates are adjusted.

In the sequence, for each sector, the entities geographically contained in it are identified and grouped into connected subgraphs (Pseudo-Algorithm 2). Note that there may be more than one connected subgraph in each sector. Thus, the largest connected subgraph of each sector is chosen as the main connected subgraph of that sector and the remaining subgraphs are relinked to one of the main subgraphs. The relink is performed between the subgraph entities closest to the largest main subgraph that may form a new connected subgraph.

Pseudo-Algorithm 2 Allocates Entities

Require: $sectors \Leftarrow$ Created Sectors

```
Identify the entities within each sector
Identify the largest connected subgraph within each sector
Allocate the remaining subgraphs of each sector to a sector's main graph
```

Intending to analyze the impact of the new map partitioning feature, Annibal et al. [2] have analyzed the map partitioning strategy by performing some experiments using some of the 2011 RoboCup Rescue Agent Simulation League[1] maps.

Table 1. Characteristics and results of the map partitioning [2]

Characteristics and Maps	Berlin	Istanbul	Kobe	Paris	VC
Dimension (Megapixel)	2.2 x 1.6	1.3 x 1.0	0.5 x 0.3	1.0 x 1.0	0.4 x 0.4
Number of Entities	4811	4581	2251	4643	3217
Police agents	6	11	20	30	25
Number of Sectors	6	11	20	30	25
Average (Entities/Sector)	802	417	113	155	129
StdDev (Entities/Sector)	140	299	73	115	47
Average/StdDev	17.46%	71.70%	64.60%	74.19%	36.43%

Given the characteristics of the 5 maps used in the tests and using the number of Police Forces as the number of sectors, the average number and the standard

[1] http://roborescue.sourceforge.net/results2011/index.html

deviation of entities per sector was calculated for each map as shown in Table 1. Based on these results, it was possible to infer that VC and Berlin maps have shapes more likely to fit rectangular sectors.

A number of simulations using a team with Map Partitioning and another one without it served as input to the Wilcoxon's Rank Sum Test, in order to compare some key performance indicators, such as the number of civilians found during the whole execution and the step in the simulation the first fire was found. Even though it was not possible to show any statistically significant improvement, the use of the Map Partitioning showed better results in most cases for all metrics analyzed. More details can be found in [2].

However, considering that the current version of the partitioning algorithm divides the map on rectangles based only on the number of Police Forces and the map dimension, we decided to develop a new approach that changes the partitioning to perform the divisions based on refuges other than the number of Police Forces. On the new version, one Police Force shall be assigned to each refuge partition. As before, the Police Forces left out of the partitioning shall be used to help other agents on their actions.

4 Communication

Communication is usually a limited resource in a disaster situation, nevertheless such resource is extremely useful for coordination purposes and sharing of information. Those characteristics are very well reflected in the RCRS platform with the limited bandwidth and the probability of message loss and channel failure.

In order to overcome those limitations, we implemented several techniques that allow a better use of the resources available and circumvent any problem that can be experienced during the simulation.

The first improvement incorporated is the use of Adaptive Huffman coding [7], which allows the data compression and transmission of more data over the same amount of bandwidth. The Adaptive Huffman coding is an adaptive technique based on Huffman coding [4] used for data compression in real time, since it permits building the code as the symbols are being transmitted, having no initial knowledge of source distribution, that allows one-pass encoding and adaptation to changing conditions in data.

Another improvement is the interleaved use of the channel by different agents depending on their IDs, where agents with even IDs transmit on even cycle, while the others transmit on odd cycles. Despite of the benefit of not overload the channel, such technique may cause a delay on information transmission, because of that we apply such technique only when the channel bandwidth is considered insufficient for the data transmission, which is still in the analysis phase.

5 Conclusion

This paper presented a description of the strategy implemented in the LTI Agent Rescue team for the RoboCup Rescue 2013. The new strategy has some differences from the one implemented for RoboCup 2011 mainly related to the map exploration, the coordination approach, and the communication efficiency. The map exploration proposed is based in a map partitioning technique used to avoid that specific regions of the map stays unexplored. The coordination approach was changed from a hybrid to a distributed one, making the agents completely autonomous on their decisions and actions. The increase on the communication efficiency was obtained by the application of several techniques to avoid channel overload and to allow a better use of the resources available.

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References

1. W. Blanchard, L. G. Canton, C. L. Cwiak, K. C. Goss, D. A. McEntire, L. Newsome, M. D. Selvers, E. A. Sorchik, K. Stenson, J. E. Turner, III, W. L. Waugh, Jr., and D. West. Principles of emergency management supplement. Technical report, International Association of Emergency Managers, 2007.
2. A. B. M. da Silva, L. Nardin, and J. S. Sichman. Um método baseado em particionamento para exploração de ambientes de desastre. *Encontro Nacional de Inteligência Artificial*, 2012.
3. E. H. Durfee and V. R. Lesser. Partial global planning: A coordination framework for distributed hypothesis formation. *IEEE Transactions on Systems, Man, and Cybernetics*, 21(5):1167–1183, sep/oct 1991.
4. D. A. Huffman. A method for the construction of Minimum-Redundancy codes. *Proceedings of the IRE*, 40(9):1098–1101, 1952.
5. H. Kitano, S. Tadokoro, I. Noda, H. Matsubara, T. Takahashi, A. Shinjou, and S. Shimada. Robocup rescue: Search and rescue in large-scale disasters as a domain for autonomous agents research. In *Proceedings of the IEEE International Conference on Systems, Man, and Cybernetics*, volume 6, pages 739–743, Tokyo, Japan, October 1999. IEEE.
6. A. H. Pereira, L. G. Nardin, A. A. F. Brandão, and J. S. Sichman. LTI Agent Rescue team: A BDI-based approach for Robocup Rescue. In *Proceedings of the RoboCup 2011*, Istanbul, Turkey, 2011.
7. J. S. Vitter. Design and analysis of dynamic huffman codes. *J. ACM*, 34:825–845, 1987.