FC PORTUGAL: DEVELOPMENT AND EVALUATION OF A NEW ROBOCUP RESCUE TEAM

Luís Paulo Reis[1,2] Nuno Lau[3,4] Francisco Reinaldo[1,2,5] Nuno Cordeiro[1,2] João Certo[1,2]

[1]LIACC – Artificial Intelligence and Computer Science Lab., Univ. Porto, Portugal
[2]FEUP – Faculty of Engineering of the University of Porto, Portugal
[3]IEETA – Institute of Electronics and Telematics Engineering of Aveiro, Portugal
[4]DETI – Electronics, Telecommunications and Informatics Department, Univ. Aveiro, Portugal
[5]GIC – Computer Intelligence Group, UnilesteMG, Minas Gerais, Brasil
http://www.fe.up.pt/~rescue

Abstract: FC Portugal Rescue team is the result of a cooperation project between the Universities of Aveiro and Porto in Portugal. Following previous collaborations of these two Portuguese Universities in RoboCup simulation league and associated competitions, this project intends to fully adapt the coordination methodologies developed by FC Portugal simulated soccer team to the search and rescue scenario. After FC Portugal's first successful participation in RoboCup rescue simulation league (Osaka, 2005), the team aimed at introducing new high-level strategic analysis tools in the Rescue league and developed FCPx tool. This tool enables an easy comparison of different teams' strategies, and the use of learning methodologies for high-level strategic decisions in rescue. The tool also enabled us to evaluate our coordination methodologies, analysing the results achieved in several rescue parameters, and conclude that they are very promising for the search and rescue domain. FC Portugal Rescue team results are very promising achieving first place in RoboCup European Championship 2006 (Dutch Open) held in Eindhoven.

Keywords: Multi-Robot Systems, Artificial Intelligence, Agents, Simulation, Cooperation, Distributed Simulation.

1. INTRODUCTION

RoboCup was created as an international research and education initiative, aiming to foster artificial intelligence and robotics research, by providing a standard problem, where a wide range of technologies can be examined and integrated.

It is currently divided in three major categories: soccer, rescue, and junior; each with its different leagues. Due to its prominence, soccer was the main motivator behind RoboCup. Being an extremely popular sport across most of the globe, it is able to attract people from different countries, cultures and religions into the same competition. Furthermore, it presents interesting scientific challenges, mostly because it is a team game, mingling individual efforts with collective strategy. On the other hand, Junior was created to give younger students a chance to participate, promoting their interest in the field with several entertaining challenges. Last, but certainly not least, came Rescue.

The huge success of the RoboCupSoccer international research and education initiative led the RoboCup Federation to create the RoboCupRescue project focussing on Urban Search and Rescue (USAR) operations. With the intention of using the scientific knowledge developed, and apply it in a socially significant domain, two new RoboCup Leagues were created on this category: RoboCupRescue Robot League and RoboCupRescue Simulation League. A new league starting in 2006, called Virtual Robots, is expected to bridge the gap between these two.

USAR operations in large-scale disasters are serious and very difficult tasks presenting several challenges from a scientific point of view. Unprepared cities may suffer tremendous consequences in a natural catastrophe as was reported in Kobe's earthquake in 1995, the 2004 Indian Ocean tsunami or, more recently, hurricane Katrina's destruction of New Orleans. Every city needs an emergency plan, to reduce the loss of human life in a natural disaster. In recent years, staggering technological breakthroughs brought some science fiction dreams closer to us. The innovations in robotics and artificial intelligence have opened doors, and allowed for a complete new use of rescue robots in emergency plans.

The RoboCupRescue Simulation League consists of a simulated city in which heterogeneous simulated robots, acting in a dynamic environment, coordinate efforts to save people and property. Heterogeneous robots in a multi-robot system share a common goal, but have different abilities and specializations, adding further complexity and strategic options. These systems can manifest self-organization and complex behaviors even when the individual strategies of all the robots are simple. Furthermore, the simulated environment behaves in a dynamic way, depending mostly on internal variables describing its current state, and on the functions describing its evolution. It is mostly outside the control of any single robot and the ability to exert any significant change requires coordinated action towards defined goals.

The team-programmed robots are of three different types: Fire Brigades, Police Forces and Ambulance Teams. Fire Brigades are responsible for extinguishing fires; Police Forces open up blocked routes; and Ambulance Teams unbury Civilians trapped under debris. Each of these types of robots is coordinated by an intelligent centre responsible for communication and strategies. In order to obtain a good score, all these robots work together to explore the city, extinguish fires, and unbury Civilians.

The RoboCupRescue Simulation League allows the development of advanced artificial intelligence, applied in multi-robot search and rescue scenarios. The acquired knowledge can then be applied, together with the advances introduced in the RoboCupRescue Robot League, to create highly intelligent, dynamic and adaptable robot teams, in real-world rescue scenarios. Although this project is mostly comprised of mid to long term objectives, some of the technology developed was already tested in the field, most notably in search of victims on the flooded city of New Orleans, after the destructive passage of hurricane Katrina, in 2005.

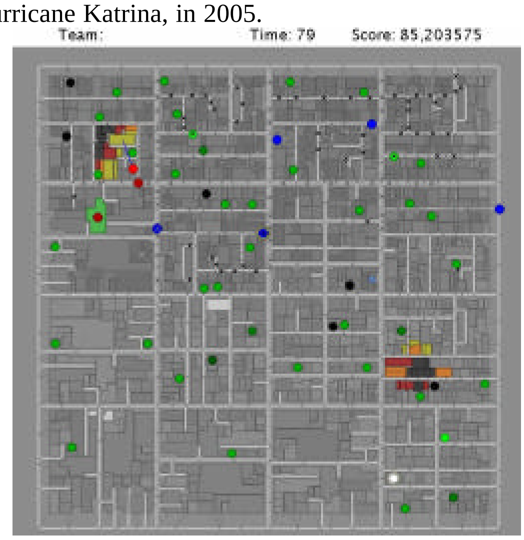

Fig. 1. RoboCup Rescue Simulated Environment.

The simulated environment (Fig. 1) is composed of several sub-simulator modules such as the fire simulator and blockade simulator. This structure allows for independent module development, permitting the addition of new modules and making the simulator system more realistic. Presently, the simulation lasts for the equivalent to 72 hours after a big catastrophe, during which the virtual robots try to achieve a balance between saving civilians and avoiding the city destruction.

For robotics and multi-robot systems researchers, RoboCup Rescue works as a standard platform that enables easy comparison of research results. The problem introduced by RoboCup Rescue brings up several research challenges that go from Intelligent Robotics to Multi-Robot Systems (MRS) research. These research challenges include real-time flexible planning, multi-robot coordination and team formation, low-bandwidth multi-robot communication, path planning and navigation, heterogeneous resource allocation and machine learning at the team level.

Our team aims to apply the knowledge and research results acquired in the RoboCupSoccer competitions, adapting successful coordination methodologies from the Soccer Simulation League to the Rescue Simulation League.

This paper is organized as follows. Section 2 presents a brief description of our team development and low-level decision processes. Section 3 describes our high-level coordination mechanisms. Related work concerning other rescue approaches and tools is discussed in section 4. Section 5 briefly describes our FCPx strategic analysis tool showing some of its potentialities. Section 6 presents a comparative analysis of different teams. Finally, section 7 concludes this paper and points out future work.

2. TEAM DEVELOPMENT AND LOW-LEVEL DECISION

Since we are mainly interested in researching new coordination and learning methodologies, in order to abstract from lower-level rescue simulation details we started our team by studying available source code from different Rescue Teams, mainly developed in Java programming language like YowAI 2003 (Endo, et al., 2003). After some time and after gaining some experience with the simulator we decided to move to a different approach and concluded that in order to be able to run efficiently most of our planned algorithms we need a more efficient language. Thus, we moved to C/C++ code using as a reference Michael Bowling Agent Development Kit (Bowling, 2000) and SOS team source code (SOS, 2005). This conclusion is, however, contradictory with the fact that most of the more successful teams in RoboCup Rescue use Java as base language for developing their agents. However since most of our RoboCup teams are implemented using C++[1], it is a lot easier to adapt our code to a Rescue team implemented also in C++.

The RoboCup Rescue domain (Anonymous, 2004; Committee, 2000) includes six types of agents that may be controlled by each team: Fire Brigade robots; Police Force robots; Ambulance Team robots; and Control centers of three types (fire stations, police offices and ambulance bases).

Centers are responsible for message routing and global tactical reasoning for each type of virtual robot. These agents are configured initially with the team strategy and try to follow it during the rescue operation.

Our simulated robots' low-level strategy is mainly the following. At the begin of the search and rescue operation, Police robots try to free "main routes" in order to enable ambulances and fire brigades to move freely between far locations. "Main routes" are defined using previously established map strategic points and computing the distances of the free tracks to the strategic points. These points include not only fire spots and civilian refuges but also map strategic crossings. At the middle/end of the search operation

[1] FC Portugal Simulation 2D, Simulation 3D, Coach Team, FC Portus legged team and Cambada Middle-Size team are all implemented in C/C++. 5DPO Small-Size and Middle Size teams are mostly implemented in Object Pascal (Borland Delphi)

(configured on the team strategy), police forces are more concerned on freeing trapped robots and attending road clearance requests from other robots.

Ambulance strategy is fairly simple and is based on taking close civilians to refuges following known free paths. Close, severely injured (but not desperately injured) civilians are preferred for rescuing. A D* based algorithm is used in order to find the fastest free known paths for ambulance navigation in the map.

Fire combat strategy is more elaborated and is based on defining fire perimeters for known fires and on building neighbours. Fire brigades try to combat the fire using pre-defined collective plans for: attacking directly a fire, minimizing fire spread or containing the fire (using a pre-emptive approach). For example, minimizing fire spreads is based on extinguishing fires in buildings that have a large number of neighbours and fire containing is based on minimizing the size of the fire perimeter. If fire is contained, fire brigades are used to search for buried civilians in order to maximize team global scoring.

3. HIGH-LEVEL COORDINATION METHODOLOGIES

After having our low-level code reasonably stable, our research is now focused on adapting coordination methodologies, developed for our RoboCup 2000 soccer simulation league team, to the rescue domain[2]. These coordination methodologies include:

- Situation Based Strategic Positioning (SBSP). This coordination mechanism (Lau and Reis, 2004; Reis and Lau, 2001; Reis, et al., 2001) enables a team of robots to move in a coordinated way in a spatial domain, based on common apriori tactical knowledge and simple environment knowledge.
- Concept of Global Situation. A situation is a high-level analysis of the search field that must be simple to perform by all robots, resulting in common global knowledge for all robots (Reis, et al., 2001). In soccer the situation is basically something like attack, defend, our goalie free kick, etc. In a search and rescue scenario it is something like avoiding fire spreading or attacking a fire. Although in the soccer simulated domain, the concept of situation is not of primordial importance for the SBSP positioning system, in other domains like battlefield or rescue, situations are very important for positioning the virtual robots.
- Definition of a Team Strategy for a Competition. The team flexibility lies essentially on the formalization of what is strategy for a competition (Reis and Lau, 2001; Reis, et al., 2001). This strategy is composed by tactics with activation rules (based on statistical information of the performance of the team in executing the task). Tactics include several high-level parameters like the group mentality, level of risk taken, etc. and also several formations to be used in different game situations (fire attack, sustaining fire in a line, etc.).
- COACH UNILANG – A Standard Language to Coach a (Robo)Soccer Team. Coach Unilang (Reis and Lau, 2002) was the first high-level coaching language introduced in RoboCup. It enables to improve team coordination by letting a supervisor agent to define the team strategy and perform the tactical changes in the team during the execution of a cooperative task by a group of virtual robots. In a search and rescue scenario, high level a-priori definition of the team strategy is essential to coordinate the team during the disaster. Coach Unilang with several high-level modifications is used by the team to define the strategy that is followed by center agents in order to coordinate the virtual robots. Our Rescue coach is a simple application that performs off-line analysis of logfiles showing the team behaviour, and decides the strategy for each rescue operation before the start of the competition.
- ADVCOM – Intelligent Communication using a Communicated World State. Intelligent communication is crucial in RoboCup Soccer and Rescue due to the low-bandwidth available to the agents. Our communication mechanism is based on robot's ability to decide the relevance of communicating a given piece of information by comparing his world state with a world state constructed using only communication. Based on the differences between these two world states, robots decide which information to communicate (Lau and Reis, 2004; Reis and Lau, 2001).

Our research on team coordinating techniques is not limited to the RoboCup Soccer and Rescue domains and most of the methodologies developed for these domains are applicable to other domains in which spatial coordination is needed. These domains include battlefield scenarios, ecological simulations (Pereira, et al., 2004) and RoboCup robotic leagues.

4. RELATED WORK

RoboCup Rescue intends to promote research and development to this socially significant domain at various levels, involving multi-robot team work coordination, development of physical robotic agents for search and rescue, development of information infrastructures, personal digital assistants, and standard rescue simulators (Kleiner, et al., 2002). The promotion of an annual rescue challenge becomes a way to get together some different teams for searching the best planned actions to minimize the damage and to test them in a virtual city. The methodical laying of practical strategy and tactics is the key to victory.

There are several teams developing virtual robots, with advanced learning (DAMAS, 2005; Freiburg, 2005; Kleiner and Brenner, 2004; Reinaldo, et al., 2005; Ren, 2004; RoboAkut, 2005; SOS, 2005) and coordination capabilities (Caspian, 2005; DAMAS, 2005; Freiburg, 2005; Reinaldo, et al., 2005; SOS, 2005; Team, 2005a; Team, 2005b), for RoboCup Rescue Simulation. Paquet et al. (2004a) presented a very good survey concerning the use of coordination methodologies in RoboCup Rescue. Several other teams present very interesting work on applying coordination methodologies to Rescue (Anonymous, 2006; Paquet, et al., 2004a; Reis and Lau, 2001; Team, 2005b).

DAMAS Rescue team (DAMAS, 2005; Paquet, et al., 2004b) concentrates its work on improving the virtual robot's ability to extinguish buildings on fire. The ability consists in classifying the best fire to extinguish by perception learning method. Virtual

[2] FC Portugal 2000, mainly due to its new coordination methodologies, was RoboCup European and World champion in 2000, scoring 180 goals in those competitions without conceding any goal.

robots are using a global view and a specific view decision making process to choose the best fire zone to attack. Global view focuses on the various burning areas. Specific view makes use of more detailed information to choose which specific building to extinguish in the chosen fire zone. The correlation between utility, and expected reward, can be seen as an estimate of the capability to extinguish a given fire. Using perception techniques, the aim is to learn how to coordinate agents, to extinguish the most important fires in a given fire zone. In the development of the simulated robots' plan, DAMAS Rescue team used Jack Intelligent Agent programming language (Howden and Renquist, 2001), decision tree algorithms and reinforcement learning (McCallum, 1996). During the simulation, the agents use the tree, created offline, to decide the best fire zone and, inside the fire zone, the best building to extinguish. This has the effect of reducing the state space of the reinforcement learning algorithm and, thus, facilitating the learning process. Other interesting point is that Fire Brigades doesn't change target areas without a good reason to do so.

ResQ Freiburg (Freiburg, 2005; Kleiner and Brenner, 2004) deals with a sequence of planning methods. The objective is to build hierarchic commands that mean hierarchic behaviours. The goal of limiting damage to people and buildings is achieved by successfully coordinating team-mates by deliberative high-level decisions of the centres. The decision about the execution of actions is decomposed in a reactive level by the platoon simulated robots and a deliberative level by the centre agents. Agents have prediction methods instead of classical planning research. This prediction method is an evaluation function for possible targets with respect to the current state of the environment. This function is extended to use hierarchical reinforcement learning (Kleiner, et al., 2002). Centres decide task execution in the long term by allocating groups of platoon simulated robots to particular tasks. Their decision making is based on a module for state prediction and abstraction, which generates the input for a novel multi-robot planner.

Caspian uses a three phase model approach to develop their simulated robots: World Model, Dynamic Path Finding and Decision Making. The first phase is the development of a World Model. The importance of this phase is crucial as the better the model is, and better the update of that model, the better the decision will be. The model for the world is the best for the available sensory information, as every virtual robot knows everything that is sensed by other virtual robot. As the number of messages each robot can listen is limited, is up to the centres to collect every virtual robot's messages, and other centre agent messages, and send a new one with all the new (based on timestamp) information. Decision Making is only done in virtual robots, each of them as a priority assigning algorithm which chooses the most important (homogeneous) job. Each Police Force virtual robot is assigned a zone to work on. Ambulance Teams always work collectively when rescuing. Their task coordination is handled by a leader. If there are no civilians to rescue in the world model, each ambulance robot is assigned a zone to search. Fire Brigade behaviour is similar to the one on Ambulance Teams, with the exception that, some times, they get separated into two or more groups.

SOS team (SOS, 2005) develops a general-purpose rescue virtual robot for implementing high-level strategies and learning algorithms. The SOS simulated robot has a state-based architecture with an explicit state-selection and state switching policy. It uses two path-finding modules that are D* and Dijkstra's algorithm. The search for burning buildings and buried civilians is done by clustering the search function space, into regions of equal size. Using the idea of Kohonen's network (Kohonen, 1987), a Voronoi diagram is constructed from those clusters. Robots are assigned regions extracted from the diagram. Tasks are prioritized according to their importance. The Fire Brigade virtual robots use a two level priority scheme for increasing the locality of successive tasks, and reducing the amount of time wasted on move actions. After defining a Fiery Region as a connected group of burning buildings, firstly the agents are assigned to a region and secondly to a building on fire. A method of Reinforcement Learning based on Q-Learning is used by Fire Brigade robots, which suffer awards or penalties according to their efficiency in performing tasks. Police Force robots perform actions by use of centralized and decentralized decision-making rules. After the simulation is started, the Police Office assigns some Police Forces to clear the blocked ways that are around a discovered fire focus. These routes will be used to facilitate the free movement of agents around these critical spots. When no jobs are received from the Police Office, Police robots scout for fire and buried civilians. In order to decide the best ways to clean, SOS uses a concept of cell temperature that reflects the importance for the overall performance of the team: the higher the temperature the more important and obstructed is that piece of terrain, therefore the agents try to lower the temperature of the hottest cell to an acceptable level. The ambulance teams use an algorithm to estimate the remaining lifetime of injured civilians. This estimation is achieved through the use of a 3-layer Back-Propagation Neural Network. In this case, only injured citizens are rescued.

RoboAkut (RoboAkut, 2005) is concerned to achieve effectiveness in virtual robots with inference mechanisms of and cooperative learning. Each robot is capable of deciding for itself when there is no support from other robots. The robot makes use of the sensory information he obtains to learn the state of the environment and, consequently, to decide on the actions to perform. In the routing module, the structural information provided to a robot includes the positions and neighbours of each building and road in the environment. A* search is carried out for finding a path from the source to destination. There is a limit on the depth of the search tree for safety. In learning module, twofold kinds of learning are used, Table

Based Q-Learning and Neural Networks. Reinforcement Learning is used as the learning module by all team robots. Each robot learns from the results of the actions it does. Having several methods of reward, one method is Q-value. In dynamic environment with further unknown states, Feed-forward is the best choice in emerging behaviour because is able to give more flexibility.

5. FCP EXTENDED FREIBURG 3D VIEWER

FCPortugal eXtended Freiburg 3D viewer (FCPx) tool (Cordeiro, et al., 2006) was developed over the simple logging features on Freiburg's 3D viewer (Kleiner and Göbelbecker), extending its ability to analyze and compare different teams. A critical aspect in evaluating and comparing performance is having the information stored in a flexible, adaptable form. If the data can be easily imported into a spreadsheet, it becomes easy to build, and analyze, tables and comparative charts. From this point onward, the versatility of this solution gives the programmer endless possibilities.

Our initial effort went into acquiring as much data as possible from the simulation. A large amount of parameters is directly obtained from the log file, while some other are calculated using those previously gathered. Some values are kept in both absolute and percentage form, so that users may have a relative idea of the action developments, simplifying the comparison between maps and teams. Some of the numbers are, therefore, redundant. However, the effortless comparison achieved justifies that. Also worth mentioning is the focus on expandability. It is possible to add a new parameter with little effort, besides the one required for its characterization.

FCPx extracts data to a flexible organized file, presenting several opportunities for data analysis. As a proof of concept and as a means to show the usefulness of the tool, a comprehensive spreadsheets was created, allowing the detailed analysis of rescue teams. The tool usefulness was proved just after its introduction in the rescue community. Several teams use it now to compare their different strategies and to compare their best strategies with other teams' strategies. Also, its open source nature and its integration into the known Freiburg's 3D viewer makes it a very easy to extend tool. It enables to analyse team strategies in a very easy way and conclusions can be drawn and directions set by a simple analysis of tables and charts. What took before several simulations, detailed manual analysis and great attention, to be determined, can now be done in minutes. Using the files generated, it is a simple endeavour to create personalized spreadsheets, to evaluate a single set of parameters in different teams.

We hope this tool may solve or simplify some of the issues associated with improving a rescue team. By using a different tool to run a set of consecutive simulations it becomes possible to leave a machine running simulations with different team strategies, for an extended period of time, while the developer focus on different tasks. Later analysis can be done in an easy, systematic fashion, allowing faster and better informed decisions, concerning development paths.

The tool's webpage has seen quite some traffic for such a restricted community. The main page had over four hundred visits and the download page has been seen over a hundred times. It was, nevertheless, expected, since FCPx fills a gap which had been previously mentioned several times in on-line discussion.

Being the first release of this tool, only groups of virtual robots of the same kind are analyzed. Future development will be oriented into analyzing the team virtual robots as individuals, and as such the tool will allow a greater perception off exceptional situations that led to a poorer performance.

6. RESULTS COMPARISON AND ANALYSIS

Comparison between Rescue teams (RoboCup 2005) is a good indication of the progress achieved and allows perceiving the most important differences between teams. RoboCup Rescue has an open source policy, it allows any team to analyze its weaknesses and, finding a team which performs better, adapt their strategies. For this purpose, the above discussed tool FCPx was used to extract the relevant data.

The main values required for a simple comparison are the ones most likely to influence the score and are calculated by considering *Sint* (amount of health points of all agents at start) and *Bint* (total undamaged area at start). At any given time step, the following values are obtained: number of living agents (*P*), remaining health points of all agents (*S*) and total undamaged area of buildings (*B*). The score *V* is calculated using Eq. 1 (Akin, et al., 2004).

$$V = \left(P + \frac{S}{Sint} \right) * \sqrt{\frac{B}{Bint}} \tag{1}$$

Analysing Eq. 1 it can be perceived that the main influence to the score comes from casualties. Any deceased civilians take a heavy toll on the score and the reason for their death should be understood. The other parcel of the equation involves the amount of building area destroyed. Although less important, since the equation minimizes the importance of buildings, fire can also reduce the score by burning civilians to death, which forces Rescue teams to take a large number of factors into consideration when trying to contain the flames. The values chosen for comparison are, therefore: Final Score (FS); Points Lost Due to Casualties (PLDC); Points Lost Due to Burned Buildings (PLDBB); Total Number of Rescue Agents Killed (TNRAK); Percentage of Civilians Killed by Fire (PCKF); Percentage of Civilians Killed by Debris and Percentage (PCKD) of Civilians Alive at the End of the Simulation (PCAES). This information can be analysed in Tables 1 and 2.

Table 1. Team Comparison I

	FC Portugal	Caspian	Impossibles
FS	64.71	67.51	70.36
PLDC	28.44	27.84	24.43
PLDBB	22.85	20.65	21.21
TNRAK	1	0	0
PCKF	27.59%	29.89%	19.54%
PCKD	8.05%	5.75%	11.49%
PCAES	64.37%	64.37%	68.97%

Table 2. Team Comparison II

	FC Portugal	MRL	Kshitij
FS	64.71	60.73	61.52
PLDC	28.44	34.42	31.69
PLDBB	22.85	20.85	22.79
TNRAK	1	1	0
PCKF	27.59%	24.14%	28.74%
PCKD	8.05%	19.54%	12.64%
PCAES	64.37%	56.32%	58.62%

From these tables, some conclusions about FC Portugal's strong and weak points can be drawn. The weakest point is the fact that a rescue virtual robot died. His death could be prevented by fine-tuning risk parameters, and thus avoiding the direct score loss. Additionally, his extra actions could have helped achieve a better score. The strong points in our team are the low Percentage of Civilians Killed by Debris (PCKD) and the high Percentage of Civilians Alive at the End of the Simulation (PCAES) which are, in some way, directly related. This shows that our ambulances are doing a good job setting up the detection of buried civilians and efficiently scheduling their rescue.

7. CONCLUSIONS AND FUTURE RESEARCH

The first conclusion is that like in other RoboCup leagues, high-level coordination methodologies are the main distinctive factor in Rescue competitions. Configurable Flexible Strategies and SBSP, now used by most of RoboCup Soccer Simulation teams, seem to be very promising coordination methodologies also for Rescue. We also plan to fully adapt, implement and correctly instantiate (for the rescue domain) other coordination methodologies in our FC Portugal team for the next RoboCup competitions. The first results of this work were very promising and FC Portugal was European Champion in Dutch Open 2006 Rescue Simulation competition held in Eindhoven, Holland, 7-9 April 2006.

FCPx tool's usefulness was proved just after its introduction and is now used by several teams to test different strategic options and to compare their best approaches with other teams. Also, the tool's open source nature and its integration into the known Freiburg 3D viewer make it straightforward to extend. The tool enables the effortless analysis of team strategies and allows a systematic study of rescue teams and strategies, permitting faster and better informed decisions, concerning development paths.

ACKNOWLEDGEMENTS

This research was supported by FCT under grant # POSI/EIA/63240/2004. The authors wish to thank the Portuguese National Science and Technology Foundation for the fellowship granted. The authors also wish to thank LIACC, IEETA, FEUP and the University of Aveiro for their support to the project and the SOS and Freiburg teams for releasing their source codes that were very useful to us.

REFERENCES

Akin, H. L., et al. (2004). Robocup 2004 Rescue Simulation League Rules, RoboCup Rescue Tec. Com. online, available at: http://robot.cmpe.boun.edu.tr/rescue2004/.

Anonymous (2004). RoboCup Rescue 2004 Homepage, online, available at: http://robot.cmpe.boun.edu.tr/rescue2004/.

Anonymous (2006). RoboCup Int. Project Homepage, online, available at: http://www.robocup.org/.

Bowling, M. (2000). Robocup Rescue: Agent Dev. Kit, available at: http://www-2.cs.cmu.edu/~mhb/research/rescue/, Dep. Comp. Science, Univ. Alberta, Alberta.

Caspian (2005). Caspian Rescue Homepage, online, available at: http://caspian.iust.ac.ir/.

Committee, R. (2000). RoboCup Rescue simulator manual v0.4, The RoboCup Rescue Technical Committee,

Cordeiro, N., et al. (2006). FCPx Homepage, University of Porto, online at: http://www.fe.up.pt/~rescue/FCPx

DAMAS (2005). DAMAS Rescue Homepage, online, available at: http://www.damas.ift.ulaval.ca/projets/RobocupRescue/

Endo, H., et al. (2003). *YowAI2003, source code*, online, available at: http://ne.cs.uec.ac.jp/~hiroki-e/.

Freiburg, R. (2005). Rescue Freiburg Homepage, online, available at: http://gkiweb.informatik.uni-freiburg.de/~rescue/sim/

Howden, N. and R. Renquist (2001). Jack Intelligent Agents - Summary of an agent infrastructure. In: *5th Int. Conf. on Autonomous Agents*. Montreal, Canada.

Kleiner, A. and M. Brenner (2004). ResQ Freiburg: Deliberative Limitation of Damage, online available at: http://www.informatik.uni-freiburg.de/~rescue

Kleiner, A., et al. (2002). Towards a life-long learning soccer agent. In: *Proc. Int. RoboCup Symposium '02* . Fukuoka, Japan.

Kleiner, A. and M. Göbelbecker Rescue3D: Making rescue simulation attractive to the public, Univ. Freiburg, online available at: http://kaspar.informatik.uni-freiburg.de/~rescue3D/3dview.pdf.

Kohonen, T. (1987). *Self Organization and Associative Memory*, Springer-Verlag, Berlin.

Lau, N. and L. P. Reis (2004). FC Portugal Homepage, online, available at: http://www.ieeta.pt/robocup.

McCallum, A. K. (1996). Reinforcement Learning with Selective Perception and Hidden State. PhD Thesis. University of Rochester, Rochester, New York

Paquet, S., et al. (2004a). Comparison of Different Coordination Strategies for the RoboCupRescue Simulation. In: *Proc. 17th Int. Conf. on Industrial & Engineering Applications of AI & Expert Systems* Vol. 3029, pp. 987-996. Springer LNAI, Ottawa, Canada

Paquet, S., et al. (2004b). DAMAS-Rescue Description Paper. In: *RoboCup-2004: Robot Soccer World Cup VIII* (Nardi et al. (Ed)), Vol. 3276, pp. Springer, Berlin,

Pereira, A., et al. (2004). Agent-Based Simulation of Ecological Models. In: *Proc. 5th Workshop on Agent-Based Simulation* (Coelho, H. and B. Espinasse. (Ed)), pp. 135-140. Lisbon

Reinaldo, F., et al. (2005). Applying Biological Paradigms to Emerge Behaviour in RoboCup Rescue Team. In: *Progress in Artificial Intelligence: 12th Portuguese Conf. on AI, EPIA 2005* (Bento et al. (Eds)), Vol.3808, pp.422-434, Springer, Covilha, Portugal.

Reis, L. P. and N. Lau (2001). FC Portugal Team Description: RoboCup 2000 Simulation League Champion. In: *RoboCup-2000: Robot Soccer World Cup IV* (Stone, P., T. Balch and G. Kraetzschmar. (Ed)), Vol. 2019, pp. 29-40. LNAI Springer, Berlin.

Reis, L. P. and N. Lau (2002). COACH UNILANG - A Standard Language for Coaching a (Robo)Soccer Team. In: *RoboCup-2001: Robot Soccer World Cup V* (Birk, A., S. Coradeshi and S. Tadokoro. (Ed)), Vol. 2377, pp. 183-192. LNAI Springer, Berlin.

Reis, L. P., et al. (2001). Situation Based Strategic Positioning for Coordinating a Simulated RoboSoccer Team. In: *Balancing Reactive and Social Deliberation in MAS* (Hannebauer, M., J. Wendler and E. Pagello. (Ed)), Vol. 2103, pp. 175-197. LNAI Springer, Berlin.

RoboAkut (2005). RoboAkut Homepage, online, available at: http://robot.cmpe.boun.edu.tr/rescue/.

SOS (2005). SOS Homepage, Amirkabir Univ. Technology, online, available at: http://ce.aut.ac.ir/~sos/.

Team, B. S. (2005a). Black Sheep Team Homepage, online, available at: http://www.cs.auckland.ac.nz/~roboteam/.

Team, H. (2005b). Hinomiyagura Team Homepage, online, available: http://sakura.meijo-u.ac.jp/ttakaHP/MeijoRescue/