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RoboCup Rescue: Search and Rescue in Large-Scale Disasters as a Domain for Autonomous Agents Research

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Abstract

Disaster rescue is one of the most serious social issue which involves very large numbers of hetergenious agents in the hostile environment. RoboCup-Rescue intends to promote research and development in this socially significant domain by creating a standard simulator and forum for researchers and practitioners. While the rescue domain intuitively appealing as large scale multi-agent domains, it has not yet given through analysis on its domain characteristics. In this paper, we present detailed analysis on the task domain and elucidate characteristics necessary for multi-agent systems for this domain.

1 Introduction

In this paper, we propose RoboCup-Rescue, as a secondary domain for RoboCup activities [Kitano, et al., 1997]. The aim of RoboCup-Rescue are (1) to ensure smooth transfer of technologies invented through RoboCup activity to a socially significant real world domain, (2) to establish a domain which complements features that are missing in soccer, and (3) to examine fundermental principles of teamwork and real-time multi-agent systems by having multiple domains with certain commonalities.

Domain characteristics of Soccer, Rescue, and Chess are illustrated in Table 1.

RoboCup Rescue consists of a simulator league and a real robot league. The simulator league focuses on strategy planning and team coordination, whereas the focus of real robot league will be on capability of individual robots in rescue operation, and how these robots collaborate to accomplish specific tasks.

Surprisingly, there is no comprehensive simulator for disaster and rescue operations. We consider that development of a comprehensive simulator which enables simulation of multi-agent rescue operation contributes to quality and effectiveness of actual rescue operation in the long run. By developing an integrated and comprehensive simulator for large scale disaster rescue, numbers of different approaches can be compared on which strategies and tactics best save people and properties. With the progress of multi-agent systems research, technologies and methodologies invented can actually be applied to real search and rescue system that commends fielded personnel and robots. At the same time, autonomous systems, semi-autonomous systems, and human with wearable-computers at disaster site can be interlinked with high-level mission planner to carry out optimal rescue operations.

While there are two categories in RoboCup-Rescue that are interlinked, this paper focus on research issues in RoboCup Rescue simulator league. The goal of this paper is to present detailed analysis of disaster rescue domain from AI perspectives, and to elucidate necessary characteristics of multi-agent and planning systems.

Therefore, this paper consists of three major parts, (1) analysis of the task domain, (2) identification of simulator architecture, and (3) identification of requirements for AI systems for rescue operations.

2 Domain Characteristics

A brief scenario of what may happen in actual disaster will help us visualize characteristics of the disaster rescue domain,

At 5:46AM of January 17, 1995, a large earthquake of a moment magnitude 6.9 hit Kobe City, Japan, killing over 6,000 people, injured at least 300,000, and

	Rescue	Soccer	Chess
Number of Agents	100 or more	11 per a team	—
Agents in the team	Heterogeneous	Homogeneous	—
Logistics	Major Issue	No	No
Long-Term Planning	Major Issue	Less Emphasized	Involved
Emergent Collaboration	Major Issue	No	No
Hostility	Environment	Opponent Players	Opponent
Real-Time	Sec. - Min.	mSec.	No
Information Access	Very Bad	Reasonably good	Perfect
Representation	Hybrid	Non-Symbolic	Symbolic
Control	Distributed/Semi-Central	Distributed	Central

Table 1: Features of Rescue, Soccer, and Chess

crushed houses for one-fifth of city's 1.5 million people. 103,521 buildings were collapsed, and only 20% of buildings were usable after the earthquake. The cost for basic infrastructure damage exceeded 100 billion dollars, and total property damage including private properties well exceeded 300 billion dollars. It was at least ten times larger devastation than 1994 Northridge earthquake hit southern California area.

With the first hit of the earthquake, houses, buildings, and other facilities were collapsed, and road, railways, and other public transportation systems are totally disrupted. Basic urban infrastructures such as electricities, gas, water supply, and sewage systems are severely damaged.

Although the earthquake was devastating, information of the scale of damage was not immediately transmitted to other part of the country. This is because information infrastructures and personnel to transmit damage report were catastrophically damaged so that they were incapable of sending precise information.

Many victim were under collapsed structures. Immediately after the earthquake, over 300 fires where reported, and they started to spread wider areas. Fire fighting were not effective as water supply was disrupted and local reservoirs were cracked so that waters leaked within hours. To make situation worse, roads and open areas which were supposed to stop fire turned into combustion pathway because debris of collapsed houses (woods) were exposed to air.

Paramedic and rescue teams had hard time arriving the disaster site due to disruption of road, collapsed buildings, and refugees. Also, there was not sufficient and accurate information on where they should be.

Aerial surveillance finally provided overall situation, but without detailed situation on the surface. The problem of the helicopter and aircraft is that the noise they create hampers ground operation to allocate victims under the collapsed houses as faint sounds victims create is the only source of information.

The lesson that we have learned from Kobe earthquake was the serious needs for robust, dynamics, and intelligent planning system and powerful human-machine systems to cope with changing situation to best save people. The scale of the disaster and speed of changing situation is far beyond human-based mission planning.

3 Immediate Contribution AI and Robotics Can Make

There are at least two major areas that AI and robotics research can make immediate contribution within the reach of current technologies, and numbers of long-range contributions with future technologies.

First, there is a potential needs for simulating and understanding the optimal or near-optimal search and rescue strategy in large scale disaster. As illustrated in the previous section, numbers of incidents and uncertaintity is far beyond human capability in making confident decisions. Providing simulators and decision-assistance system would significantly improve the quality of decision and understanding of the possible simulation to unfold. Such a simulator and decision-assistance system shall be an integrated simulation of properties and infrastructures damage, fire proliferation, refugee movement, and other factors involved, and a group of agents should be deployed to examine efficacy of specific search and rescue strategies. In future, such a simulator should be linked to mobile communication and data acquisition systems on the field. This simulation possibly involved 1,000 and 10,000 agents and events.

Second, there is immediate needs and opportunities for researchers to contribute search and rescue by building a group of robots that work as a team, each of which is specialized in specific sensing and mobility. For example, to find victims under the debris, one robot may have hexapot legs and walk over the debris and insert a rod with microphone and micro-CCD camera in between debris. Other robot may be small enough to go into the debris with CCD and infra-red camera. These robots collaboratively cover the space under the debris. To efficiently and completely cover the space, teamwork would be an essential factor. Numbers of agents involved in this scenario is perhaps less than 20, though it depends on the size of the single site.

4 Disaster Rescue Simulation System

Disaster simulation requires integration of simulation on various aspects of disaster. These includes, fire, housing and building damages, disruption of roads, electricity, water supply, gas, and other infrastructures, movements of refugees, status of victims, hospital operations, etc.

Building and Housing Damage: Simulates degree of damage of buildings and houses. When detailed simulation is to be performed, this need to be made block-by-block level and more specifically for major landmarks.

Fire: Simulates occurance of fire, and how they may spread over time. Composition of building type and weather factors will be incorporated. Also, the spreading pattern of fire need to reflect collapse of buildings and effectiveness of fire fighting. Existing simulator model this process as stochastic process of propagating heat and catching fire with thresholded functions over static terrain. They are not incorporated with damages of buildings, and efforts of fire-fighting.

Life-Line Damage: Simulates damage of roads, electricity, water supply, gas, and other infrastructure known as Life-Line. These damage simulation need to be tightly coupled with building and housing damage simulator. Currently there are a few simulator which can predict road blockage at the level of 70 - 80% [Takahashi, et al., 1998]. These simulator is not yet coupled with other simulators.

Victim Modeling Victims and refugee are critical components of the simulation. Depending on a type of the disaster, location of victims, and magnitude of the disaster, physical and mental damages victims suffer differ drastically. Reflecting difference and urgency of the victim, how to rescue these victims need to be changed. This involves time frame of the operation, a kind of paramedic first aids, hospitals that victims need to be carried, type of equipments and expertise of paramedic teams, etc.

Also, it has serious time sensitive elements. Certain type of causality has to be taken care of within very short period of time, and if paramedic team arrived much later than the time limit, the nature of operation could be very different. If victims are not seriously suffering, priority would be lower so that rescue can be direct to more urgent victims. However, saving such victims may turn out to be time critical as victims attrition gets serious or other urgent factors come out.

Refugee Behavior Modeling Refugee modeling essentially requires simulation of very large number of people who are trying to escape from disaster site, trying to find secured place, searching for family and friends. The movement of refugee is critically important because massive refugee marching to escape from the disaster site seriously blocks traffic trying to reach disaster site for rescue. It may be possible that some Artificial Life type of approach can provide reasonable simulation on this aspect. The simulation, however, need to be interactive to change of terrain. Due to collapse of building and roads, and road blockade performed by police can continuously change the terrain, and how movements of refugee are affected need to be simulated.

5 Search and Rescue Strategy

Finding out the better search and rescue strategies for large scale disaster involves the-state-of-the-art planning and multi-agent research, such as teamwork [Tambe and Zhang., 1998], planning under uncertainty [Pollack, 1998], resource-boundedness[Russel, 1995], hierarchical planning [Kambhampati et al., 1998], and real-time planning. While we cannot possibly create an exhaustive list of research issues, major issues can be envisioned as follows:

Multi-Agent Planning: This domain may involve planning and execution monitoring for over 10,000 agents, that has different physical and informational capabilities under dynamically changing hostile environment. There are several ways that planners may work. First, it may coordinate global strategy with several subordinate planners. Flexible hierarchical planning is essential to this accomplish a large scale planning. Second, planning will be done distributed manner, as disaster sites will spread over wide areas and communication in between them will be limited. Each local planning system, however, communicate with other planner and global planner to synchronize activities and up-date status achieve optimal strategy. Third, contrary to the notion of global planning system, there is a need to establish technologies to totally distributed and asynchronous planning when there is no clear global planning center exists, or even the expected global planning site is destroyed. Whether the most efficient strategy planning can be achieved by global planning with subordinate planners, or totally distributed planning suffice is a major research issue. Entire planning system may need to be flexible enough to dynamically reformulate planning strategy between the spectrum of distributed planning and hierarchical planning.

In addition, agents involved are heterogeneous. There are rescue people and robots, helicopter, vehicles, and other autonomous and non-autonomous agents.

Real-time/Anytime planning: Quite obviously the critical need for planning under real-time constraints are severe in this domain, given that the situation can change very quickly, and often for the worse. Coming up with a good plan as quickly as possible may not be good enough – a plan agent in this case should be able to provide with a plan on demand, not as quickly as possible.

Heterogeneous Agent Planner should be able to recognize capability of each agent, and coordinate then to accomplish certain tasks. It may e often the case, that capability necessary is missing in the agents available on site. The planner should be able to access potential availability of the missing features, and request the capability to be added to the agent or new agents to be participated in the team.

Robust Planning There is "fog of war" at disaster site. Much of information available to agents and decision maker is incorrect, partial, and essentially unreliable. Planning system should be able to access reliability of information, and cope with possible errors. A feature that planner to actively request information gathering would be critical. Not only information, but also actual agents may involved in accidents or disabled for various reasons. In addition, operation dispatched to agents are not guaranteed to be executed, due to unexpected hardship on site. There must be a method to cope with range of uncertaintity, yet re-plan and execute in real-time.

Mixed-Initiative Planning There will be many occasions that human rescue person will make their decision and execute search and rescue, that are not necessary consistent to the planner's plan. Planner must cope with such complex situation, and work out how to negotiate and find the best solution. At the same time, if actions taken by human rescue personnel, that is not consistent with the planner worked well, certain learning and archive capability to transfer such successful actions to other sites.

Execution Monitoring In such a hostile environment, it is not at all guaranteed that command and operators dispatched from the planner will be executed as expected. The major question are (1) how to gather information on the status of plan execution, (2) how to cope with disruption of communication, (3) how to deal with mis-information that personnel on site provided incorrect information. This issue is tightly coupled with robust planning.

Scenario-Based Planning It is totally inconceivable that we would not be unprepared for disasters. There are numbers of search and rescue scenario and doctrines, just like military planning. There are political decisions and social decision that are not easily incorporated into automated planning, and rescue strategy created by responsible officers need to be accommodated. Thus, planner must be able to use a given set of scenario, as well as creating their own plan.

Resource-Bounded Planning Search and rescue operations are always constrained by resources, such as materials, personnel, time, and other factors. For example, number of robots and personnel which can arrive specific site within the given time limit, is seriously limited by traffic, fatigue, and available agents. Planner must be able to take into account such constraints, and possibly propose plan to mitigate such constraints, while maintaining long-range strategies.

Data Collection Agents and Planning One of the major problem in disaster is, as repeated many times already, is difficulties in getting accurate information within reasonable time. There is a need for explicit planning and agent for data collection, which are coupled with agents and planner, so that necessary information can be obtained faster and more reliably. This is a totally an open issue, and have not been investigated in the past.

6 Discussions

There are numbers of different aspects of the problem that AI and robotics can contribute. Focusing on the aspect of actual robots, instead of high-level planning, following issues need to be addressed:

- robust robot systems that can go into disaster sites, which means to move around in the uneven surface and in the hostile environment.
- multiple sensing systems with flexible configurations, so that sensors can be placed and extended into debris to capture sign of victims.

- intelligent systems to automatically, or semi-automatically carry out sensor placements and self-positioning.

- multi-agent planning systems which can coordinate actions and positions of robots in the team

- human-robot interface that enables rescue person to control a team of robots for more effective operations

- interface with strategic planning systems to coordinate local operations with global operations

Ideally the system should be hierarchical, yet organized to maintain consistencies and robustness against failure of single or multiple failure of planners and robots.

Most of these issues are still the open problem for AI and robotics, and thus this domain is a rich source of inspirations which can promote not only rescue-related robotics and AI, but also to more general technologies.

7 Conclusion

In this paper, we described RoboCup-Rescue as the secondary domain for RoboCup. It is designed to ensure smooth transfer of technologies developed in current RoboCup soccer, as well as promoting innovation by itself as it complements features missing in soccer. RoboCup-Rescue has both simulation and real robot aspects, each of which initially focus on different aspects of overall activities. This paper focused on overall strategy planning aspect using a simulation. As it is clearly illustrated, RoboCup-Rescue is a rich source of research, and direct contribution to the society is expected.

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References

[Kitano, et al., 1997] Kitano, H., *et al.*, "RoboCup: A Challenge AI Problem," *AI Magazine,* spring, 1997.

[Tambe and Zhang., 1998] Tambe, M. and Zhang, W.,N "Towards Flexible Teamwork in Persistent Teams," *Proc. of ICMAS-98,* Paris, 1998.

[Pollack, 1998] Pollack, M. and Zhang, W.,N "Plan Generation, Plan Management, and the Design of Computational Agents," *Proc. of ICMAS-98,* Paris, 1998.

[Kambhampati et al., 1998] Kambhampati, S., Mali, A., and Srivastava, B., "Hybrid Planning for Partially Hierarchical Domains," *Proc. of AAAI-98,* Wisconsin, 1998.

[Russel, 1995] Russel, S., "Rationality and Intelligence," *Proc. of IJCAI-95,* Montreal, 1995.

[Takahashi, et al., 1998] Takahashi, H., Akakura, Y., Nakamoto, T., and Yoshimura, H., "Simulation of Steet Blockages Caused by Earthquake through The Analysis of the Hyougoken-Nanbu Earthquake," *Proc. of Japan Earthquake Engineering Symposium,* 1998. (in Japanese)