Intelligent GIS for Spatial Cooperation of Earthquake Emergency Response

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Synopsis

Search and rescue teams are the key field teams in earthquake emergency response. They have to work together and make decisions in order to achieve a high performance. The key challenge which they have is the spatial cooperation problem; therefore they have to determine what team must do what, where, and when. This paper tried to propose an intelligent GIS for solving the cooperation problem in the spatial environment. The spatial cooperation problem can be solved by the method of distributed task allocation and multi-agent systems. In this article we discuss the cooperation problem, its solution, and structure of IGIS.

Keywords: GIS, multi-agent systems, task allocation, search and rescue

1. Introduction

Relief and rescue (RAR) operations are the key emergency support functions (FEMA, 2008) defined for earthquake emergency response. RAR operations contain five main tasks: 1- loss assessment and data collection; 2- searching and locating victims trapped in collapsed structures; 3- rescuing and extrication; 4- initial life-saving assistances; 5- emergency medical transportation (Provisions of Tehran city council, 2003). Fig.1 shows the structure of RAR operations.

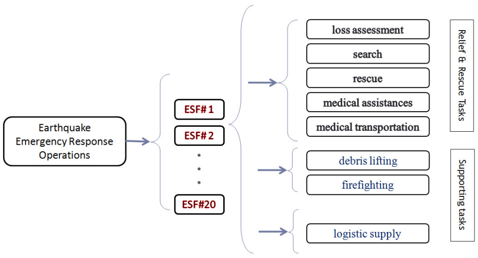

Fig. 1 Structure of relief and rescue operations

The cooperation problem is the key challenge that field human teams face in disaster affected areas. The objective of tactical decisions is to determine what team must do what task, where, and when in order to increase the efficiency of the organization.

Cooperation among teams and coordination of emergency response is a difficult problem (Chen et al., 2008). The main question of this research is that how I can achieve an efficient approach for the spatial cooperation problem (SpCP) by making decision for filed human teams in a spatial and dynamic environment.

1.1 Background

Development of emergency response systems is based on the two major approaches: the centralized approach and the distributed or decentralized approach. Multi-agent systems form the second one (Sycara, 1998).

Because of characteristics of emergency response, a number of disaster management systems (Fiedrich et al., 2007) have been developed based on multi-agent systems.

Techniques and methods of cooperation in multi-agent systems are classified in the categories: (1) task allocation, (2) coalition formation, (3) multi-agent planning, (4) communication and data sharing, and (5) negotiation.

Technique of task allocation among agents is a method for distributed problem solving. Distribution of tasks between teams answers “who must do what?”. Task distribution modes are classified into two main categories: centralized allocation and distributed allocation.

An important coordination technique of task allocation is the contract net protocol (Smith, 1980). It consists of: (1) problem recognition, (2) tasks announcement, (3) bidding, and (4) awarding.

In (Nwana et al. 1996), five reasons that necessitate coordination in multi-agent systems are stated: (1) preventing anarchy or chaos, (2) efficiency, (3) meeting global constraints, (4) distributed information, expertise or resources, and (5) dependencies between the agents’ actions. In (Malone et al., 1994), coordination is defined as the act of managing interdependencies between activities.

In the recent decade, there have increasing importance on the role of geographic information systems (GIS) (Aronoff , 1991), in emergency management systems (Vafaeinezhad et al., 2009; Sahana Software Foundation).

1.2 Research objectives

The purpose of the current paper is to propose an intelligent GIS (IGIS) that human agents use to make decisions for the cooperation problem in a spatial environment in order to increase global efficiency of the organization.

In the real situation, the IGIS is a tablet computer that includes a spatial distributed intelligent agent (SDIAgent), GIS, GPS, and wireless communication. The human agent, who is coordinator of the filed unit or team, is equipped with an IGIS to plan emergency operations. The role of SDIAgent (software agent) is to communicate with other SDIAgents for cooperation. The IGIS is an efficient approach that enables humans collaborates with SDIAgents in order to overcome challenges regarding the SpCP in a spatio-temporal environment.

2. Methodology

Defining the SpCP was the most important step in this research. Fig. 2 shows the organizational structure of emergency management. As fig.3 shows, RAR teams, RAR tasks, city damaged buildings, and time constitute components of tactical plans.

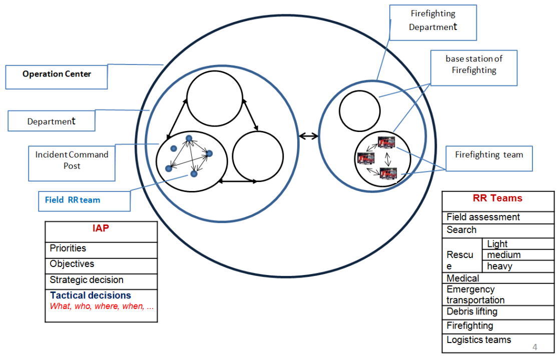

Fig.2 Organizational structure of emergency operations center

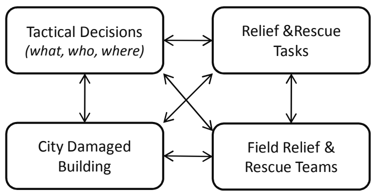

Fig. 3 Structure of a tactical plan

To model the structure of SpCP, I defined the relationship among tasks and teams. Fig. 4 shows a simplified structure of SpCP.

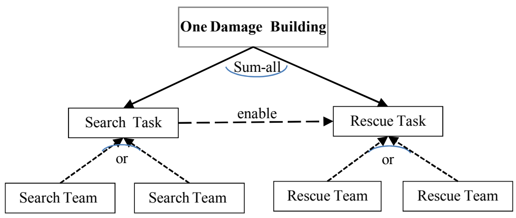

Fig. 4 Structure of SpCP for SAR operations

Search and rescue (SAR) can communicate directly in an organizational structure. Each damaged building can have only one search task and one rescue task. City damaged buildings and SAR teams disperse in geographical region so they have geo-referenced locations. Filed teams move from one location to another one through street networks to reach a damage building. One research team has the capability of doing search tasks and rescue tasks can be carried out by rescue teams. I defined an operational region for each team to control its spatial behaviors. It means that every team had to do only tasks which are located geographically within its operational region.

Interdependencies that exist among activities make emergency response more complex. For that reason, I modeled the relationship "enable" and "equality" in the simplified structure of the SpCP. The relationship "enable" specifies that when an action is carried out, it makes possibility of performing another action. As the fig. 4 shows, this relationship makes dependent a rescue task to a search task. It implies that after a search team completes the search task, a rescue team can start doing the rescue task. The relationship "equality" means that certain actions are not liked to a specific team, and can be carried out by another team. Fig. 4 shows this relationship between a rescue task and several rescue teams for the case of the damaged building. After a search team finds some trapped victims under debris, it announces a rescue request to all rescue teams in order to assign this task to the most proper one.

2.1 Structure of spatial cooperation problem solving (SpCPS)

A decentralized approach based on multi-agent systems was designed for solving the SpCP discussed before. I selected the method of distributed task allocation for the SpCP, and then I tried to deploy it by the contract net protocol. As a summary, I designed a decentralized approach based on the contract net mechanism so that search teams can allocate rescue tasks among rescue teams. Fig. 5 shows structure of human-agent teams and IGISs in a geographical environment and fig. 6 shows the structure of SpCPS.

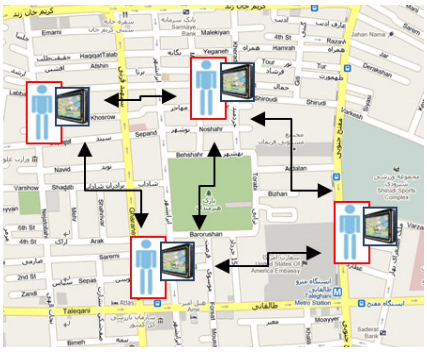

Fig. 5 Structure of IGISs in a geographical environment and mechanisms of information sharing

As fig. 5 shows, decision making and reasoning is distributed among autonomous entities (human-agent team) and each one has its local view and autonomy; but disaster information management is centralized and global so that IGISs increase efficiency of the method of task allocation.

I investigated how a human agent can collaborate and interact with a software agent as teamwork to solve the SpCP, as fig. 6 shows in detail. In fact, a human-agent team (team) consists of a human agent (human coordinator or commander of a field unit) and software agent (SDIAgents). When a team recognizes a problem that it can not carry out, the human agent asks its SDIAgent to assign it to a proper and willing team. Then SDIAgent communicates with other SDIAgents to allocate it to the best team. The main role of SDIAgents is to make tactical plans and the major role of human agent is to make strategies and interact with its SDIAgent; as a result, human-agent teamwork results in SpCPS.

2.2 Spatial distributed intelligent agents

To implement the structure of SpCPS, I had to design architecture of SDIAgents. Emergency environment is done a spatial and uncertain environment and tactical plans have a spatial-time aspect. SDIAgents allows us to implement the workflow of spatial cooperation problem by collaboration with human agents using contract net protocol.

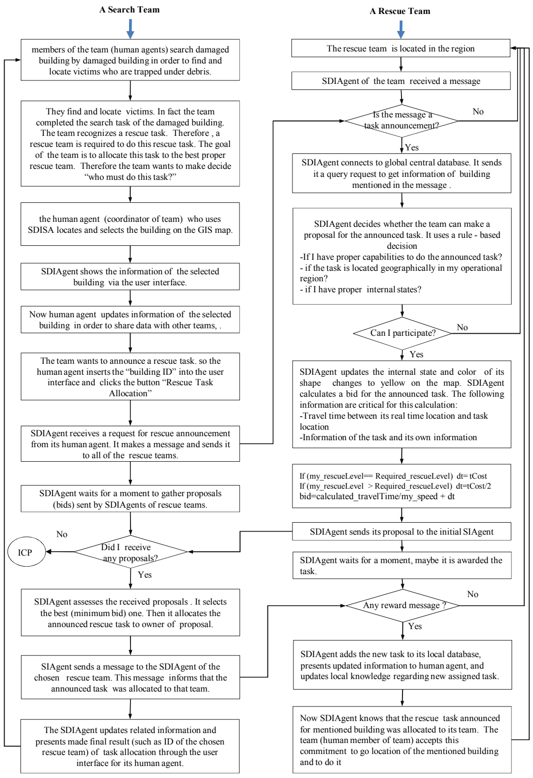

Fig. 6 Workflow of allocating a rescue task by a search team to the most proper rescue team using the contract net mechanism in the SpCP of SAR operations

Spatial distributed intelligent agents are multi-agent systems which are embedded and distributed in a geographical environment. They are referenced to a location on the earth. Therefore, spatial distribution is another characteristic of multi-agent systems and geospatial information plays a major role in their architecture for spatial cooperation. I aimed that multi-agent systems can get the advantage of GIS. Fig. 7 shows an initial architecture of SDIAgents that I designed to support the structure of SpCPS.

3. Geospatial Simulation of Intelligent GIS

To evaluate the IGISs, I developed a geospatial simulation. Castle et al. (2006) outlined the fundamental concepts of the agent-based modeling paradigm, with particular reference to the development of geospatial simulations.

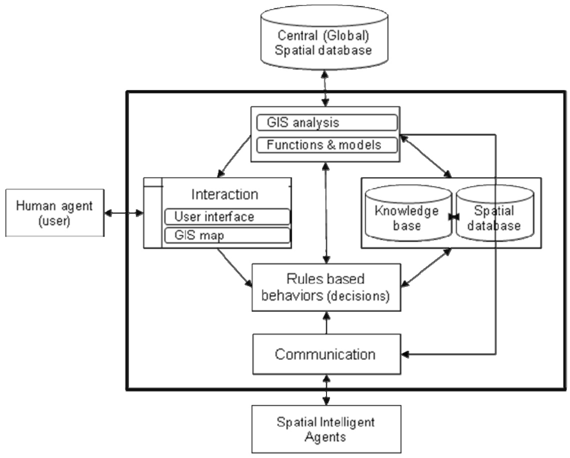

Fig. 7 Initial architecture of spatial distributed intelligent agents

To simulate the structure of SpCPS and to implement the SDIAgents, I developed a geospatial simulation using Anylogic simulation software, Java programming, and ArcGIS desktop. To embed the SDIAgents in a geographical environment, I built a global Geodatabase (Zeiler, 2000) containing city blocks, regions, operational areas, and damaged buildings data. I selected the district 17 of Tehran city as the case study region, because it was assessed as the most vulnerable one (Mansouri et al., 2010). Fig. 8 shows the geospatial simulation of IGISs for task allocation in search and rescue operations. This geospatial simulation allows us to simulate the structure of SpCPS that was discussed

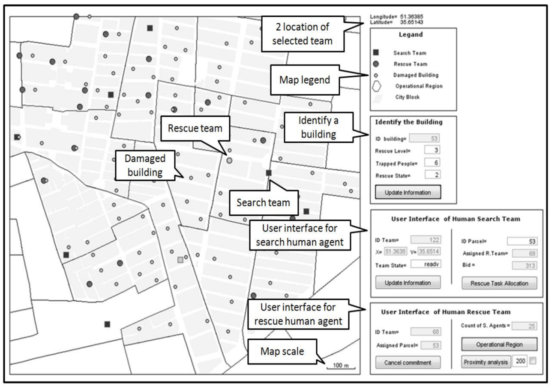

Fig. 8 Geospatial Simulation of Intelligent GIS for distributed task allocation of earthquake SAR teams

The human user of this simulation can select any team on the map to play its role. As fig. 8 shows, the user decided to be the search team with ID “122”. Its location is highlighted on the map.

Furthermore, the user interface displays internal information of the SDIAgent, so the human user can update them. Imagine that the team recognizes a rescue task for the damaged building with ID “53”. then human agent wanted to identify it on the map and update its information. He decided to allocate it to the best rescue team, so he inserts the ID of the mentioned building on the user interface and asks its SDIAgent to allocate it. The SDIAgent receives a request for a rescue task announcement, then it communicates with other SDIAgents to allocate it to the best team based on contract net mechanism. The mentioned task was assigned to the rescue team with ID “68”. If the user of simulation selects the rescue team “68”, he will be informed by its SDIAgent about a made tactical plan .As a result, the key result was a tactical decision which determined who should do what, where, and when. Over time, teams can repeat this mechanism to make others plans to complete all of RAR task in the region.

As the geo-simulation shows, decision making and planning is distributed among teams, indeed a central planning system dose not exist for allocating tasks between teams. To increase local view of SDIAgents, a global spatial database manages information of damaged buildings.

4. Conclusion

In this paper, I tried to model the structure of a SpCP which search and rescue team have in earthquake emergency response. I proposed a distributed approach based on multi-agent systems and GIS. I used the method of distributed task allocation and designed a structure to solve the problem based on the contract net mechanism. I introduced the architecture of SDIAgents. I develop a geospatial simulation to simulate IGISs for SpCPS. I tried to achieve the objectives defined for this paper and answer the key questions of this research. I achieved an initial IGIS for spatial cooperation in RAR operations.

To achieve a comprehensive SDISA, I should focus on improvement of the architecture of SDIAgents. Future woks include the methods of spatial multi-agent planning

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地震緊急対応における空間的協力のためのインテリジェントGISの設計

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要　旨

搜索救助チームは，地震の緊急対応のキーとなる。彼らは高パフォーマンスを達成するために共同作業と意思決定をしなければならない。彼らの重要な課題は，空間的な協力体制の問題であるため，彼らはチームがどこで，いつ，何をしなければならないかを決定する必要がある。本稿では，空間的に相関が及ぶ環境下での協力問題を解決するためのインテリジェントGISを提案する。空間的協力の問題は，分散タスクの割り当てやマルチエージェントシステムにより解決することができる。ここでは，協力問題と，その解決策，およびIGISの構造についての議論を展開する。

キーワード：GIS，マルチエージェントシステム，タスク配分，捜索救難システム