Simulation Modelling Practice and Theory 82 (2018) 132–146

Contents lists available at ScienceDirect

Simulation Modelling Practice and Theory

journal homepage: www.elsevier.com/locate/simpat

Using auction-based task allocation scheme for simulation optimization of search and rescue in disaster relief

Jian Tang, Kejun Zhu*, Haixiang Guo, Chengzhu Gong, Can Liao, Shuwen Zhang

School of Economics and Management, China University of Geosciences, Wuhan 430074, PR China

ARTICLE INFO

Article history:
Received 3 April 2017
Revised 19 November 2017
Accepted 22 December 2017

Keywords:
Disaster relief
Agent-based simulation
Truncated Lévy walks
Cooperative rescue
Auction
Task allocation

ABSTRACT

In order to improve the efficiency of search and rescue (SAR) in disaster relief, we optimize the SAR through agent-based simulation in this paper. The Truncated Lévy walks model is adopted to simulate rescuers' search behaviors, and we improve it to fit the disaster environment. An auction-based task allocation scheme is used to develop a cooperative rescue plan. To verify the effectiveness of the proposed scheme, we illustrate it with the case of landslide disaster relief, and simulate it in three scenarios ("fatal", "serious" and "normal"). We compare it with non-cooperative rescue plan and the rescue plan based on well-known F-Max-Sum. The simulation results indicate that the cooperative rescue plan could improve the rescue efficiency significantly, and it performs somewhat better than the F-Max-Sum-based approach in regard to some indicators. Furthermore, its low complexity has made it more appropriate for the cooperation among rescue teams than F-Max-Sum. The robustness analysis shows that search radius can affect the rescue efficiency significantly, while the scope of cooperation has little effect on the rescue efficiency. The sensitivity analysis shows that the two parameters, the time limit for completing rescue operations in one buried site and the maximum turning angle for next step, both have great influence on rescue efficiency, and there exist optimal value for both of them in view of rescue efficiency.

1. Introduction

Search and rescue (SAR) of victims in large-scale disasters is of great importance in disaster relief. The research of disaster relief has focused mostly on emergency supplies reserve, location problem, emergency transportation, resource allocation and evacuation [1–7], which has provided important theoretical foundation for disaster relief and improved rescue efficiency for sure. However, the issue of SAR in post-disaster phase has been addressed only rarely in literature, especially the issue of cooperation between rescue teams.

Search and rescue (SAR) activities are part of a complex emergency system that emerges to respond to disasters. SAR is defined as the activity of locating and recovering persons either in distress, potential distress or missing and delivering them to a place of safety [8]. Most of the topics that have been addressed in SAR are robot-assisted search and rescue [9,10]. Some topics have been focused on the maritime search and rescue [11,12]. Some researches of SAR are just about path planning and searching for survivors [13,14]. However, few of them have focused on the cooperation between rescue teams, let alone

* Corresponding author.
E-mail addresses: tangjian@cug.edu.cn (J. Tang), zhukejun@cug.edu.cn (K. Zhu).

https://doi.org/10.1016/j.simpat.2017.12.014
1569-190X/

integrating search with cooperative rescue in disaster relief. Su et al. have researched the dynamic cooperation between rescue units in disaster environments under spatial and communicational constraints [15,16].

The cooperation between rescue teams is essentially about task allocation. Many approaches for task allocation problem have been proposed, such as contract net protocol [15,17,18], intelligent algorithm-based approaches [19–21] and auction-based approaches [22–26], etc.

Contract net protocol is a market-based approach that was proposed as early as 1980 [17]. Liang and Kang [18] have proposed an improved contract net protocol for task allocation in agent-oriented Unmanned Underwater Vehicle (UUV) swarm system. Su et al. [15] employed contract net protocol for task allocation at an assembly point when adjusting group members periodically in disaster environment.

Intelligent algorithm-based approaches are also frequently adopted in this problem. Celik et al. [19] have solved a task assignment problem with greedy algorithm. Ju and Chen [20] have applied the extended labor division model of ant colony to task allocation in a dynamic environment. Wex et al. [21] have optimized the allocation and scheduling of rescue units to incidents in disaster management through several heuristics, including Monte Carlo-based heuristic.

One of the most used approaches is auction-based strategy. The items being bid for are the rescuing task. Generally, when a rescuing task is announced, rescue teams place bids on it, based on the utility of the task and the cost of performing it. The rescue teams who win the bid will perform the rescuing task [23,25,26]. Nanjanath et al. [22] have used Sequential Single Item Auctions to assign tasks to agents. Nair et al. [23] have developed two auction-based approaches, a centralized combinatorial auction mechanism and a distributed method. Kong et al. [24] have proposed a decentralized indicator-based combinatorial auction strategy for group task allocation.

Moreover, some task allocation problems have been solved through coalition formation. The sequential and holistic coalition methods proposed in [27] provided both online and offline solutions for task allocation into a group of heterogeneous mobile robots. Ramchurn et al. [28] have provided a distributed constraint optimization (DCOP) formulation of the coalition problem and solve it with the F-Max-Sum algorithm.

Although the above mentioned approaches have been successfully used in different problems, it is not appropriate to apply them directly to SAR in disaster relief. The task allocation problem arise from cooperative rescue in disaster is NP-hard problem [25]. The centralized approaches such as intelligent algorithm-based approaches are quite suitable for NP-hard problem. In such approaches, satisfactory solution for task allocation could be obtained based on the global knowledge of the environment. However, the application of these centralized approaches in disaster environment could encounter the issue of communicational constraints [29], which might cause great difficulties in gaining global knowledge and delay in decision. Furthermore, most of these approaches are unable to handle the dynamics of disaster relief. Some decentralized approaches such as Max-Sum algorithm could overcome the limitations brought by communicational constraints, and obtain good solutions for task allocation. Nevertheless, the message-passing and iteration in Max-Sum algorithm would cost a lot of time, which makes it difficult to start rescue operation at the best time.

This work aims to suggest an improved auction-based task allocation scheme for rescue cooperation in disaster relief. Auction-based task allocation scheme is a decentralized approach, and it is efficient in gaining solutions for task allocation, for its high flexibility and good fault tolerance [30]. Different from the common auction-based scheme, the opportunity cost has been taken into account when bidders make a bid. Furthermore, we have introduced adjustment in this task allocation scheme to cope with the dynamics of disaster relief. This auction-based task allocation scheme has provided a rapid way to reach cooperation to increase overall rescue teams' performance.

In this paper, we integrate search with cooperative rescue in disaster relief, and simulate it with the case of landslide rescue. We first construct a post-disaster environment based on multi-agent modeling. The survival probabilities of victims trapped in rubbles are assumed to deteriorate with time [31]. Related to the search for victims, the environment of landslide disaster is usually an area completely covered by rubbles, rocks, debris, etc. It is hard to gain any critical information of the environment (such as location of victims), thus the searching behavior is similar to free movement. Rhee et al. [32] have found that the patterns of pedestrian free movement and Lévy walks are similar in some statistical properties, so Lévy walks is applicable to modeling searching behavior. In addition, it has been proved that for randomly located targets, whether the targets can be revisited many times or not, and whether the targets are fixed or moving, Lévy walks is an efficient strategy [33–36]. Thus, we adopt the improved Truncated Lévy walks [33] to simulate rescue teams' search behaviors. Finally, we propose a cooperative rescue plan based on distributed auction mechanism, and evaluate its performance in different scenarios. The proposed rescue plan will be compared with non-cooperative rescue plan and the rescue plan based on well-known F-Max-Sum [28]. The robustness and sensitivity of our proposed cooperative plan are tested as well.

The structure of the paper is organized as follows. Section 2 introduces the problem and describes two types of agent, victims and rescue teams. Section 3 introduces the cooperative rescue plan based on distributed auction mechanism. The simulations of cooperative rescue plan are shown in Section 4. The robustness and sensitivity of our proposed cooperative plan are evaluated in Section 5. Conclusions and future directions are given in Section 6.

2. Description of multi-agent model

The disaster relief is modeled through agent-based simulation. In this model, shown in Fig. 1, two types of active agents are included, namely victims and rescue teams. The active agents can react to the environment and act on it. The tasks, i.e. the buried sites in the disaster environment, are spread randomly in an area, and they differ in some properties, such as the