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An Evacuation Decision Making Model for Firefighters in Ad Hoc Robot Network

Demin Li Jian Zou Kaikai Yue Hongyun Guan
College of Information Science and Technology
Donghua University
Shanghai 201620, China
deminli@dhu.edu.cn

Jiacun Wang
Department of Computer Science and Software Engineering
Monmouth University
West Long Branch, NJ 07762, USA
jwang@monmouth.edu

***Abstract*—Evacuation for a firefighter in complex fire scene is challenge problem. In this paper, we discuss a firefighter's evacuation decision making model in ad hoc robot network on fire scene. Due to the dynamics on fire scene, we know that the sensed information in ad hoc robot network is also dynamically variance. So in this paper, we adapt dynamic decision method, Markov decision process, to model the firefighter's decision making process for evacuation from fire scene. In firefighting decision making process, we know that the critical problems are how to define action space and evaluate the transition law in Markov decision process. In this paper, we discuss those problems according to the triangular sensors situation in ad hoc robot network and describe a decision making model for a firefighter's evacuation the in the end.**

Keywords- Ad hoc robot network, information fusion, directed graph, evacuation for a firefighter)

I. INTRODUCTION *(HEADING 1)*

Evacuation, especially for a firefighter in complex fire scene is a challenge problem. In this paper, we discuss how to evacuate for a firefighter in fire scene. On the complex fire scene, a firefighter's searching and rescuing victims is a dangerous process. Bashyal and Venayagamoorthy [1] let a human remotely control one of the robots in the swarm for searching. Hashimoto et al. [2] discussed a human being participating as a swarm member for search and rescue. Ulf Witkowski etc. [3] presented an ad-hoc network communication infrastructure for multi-robot systems in disaster scenarios. The main objective of the ad hoc network is to provide the team of robots and humans with robust communications links inside a building full of smoke. Thibault Kruse etc. [4] introduced a robot navigation approach that takes into account human-centered requirements and the collaborative nature of the interaction between the human and the robot. The paper only discussed the path planning problem of robots, but did not consider the human path planning problem. Penders etc. [5] presented the technology developed for a swarm of robots assisting a firefighter, and discussed robots just like nodes in ad hoc networks how to establish communication network and how to localize and map the fire scene. But the paper did not discuss how a firefighter to get and use the information about fire scene to navigate. In the paper [6,7], we use smoke density gradient and dynamic triangular network to establish directed graph, and discuss that firefighter how to select safe path to depart. Due to the dynamics on fire scene, we know that the sensed information in ad hoc robot network is also dynamically variance. So in this paper, we adapt dynamic decision method, Markov decision process, to model the firefighter's decision making process for firefighter's evacuation from fire scene.

The remaining of the paper is organized as follows. In section two, we discuss ad hoc robot network model, including dynamic triangulation method and communication protocol selection. In section three, for decision making use, we discuss Markov decision process related to firefighting situation. Using information fusion and Markov decision process, in section four, we describe information fusion based decision making for a firefighter's evacuation. We conclude in section five.

II. AD HOC ROBOT NETWORK MODEL

Fig. 1 in [8] shows a sketch of an environment, covered by the ad-hoc local network build by robots. Robots are represented as circles, and the communication links among them are indicated by dashed line segments. Two white circles represent the beacons positioned as the entrance to the site. Whereas other beacons can change their positions, these two positions might be preserved, as beacons at these positions can have several missions. They will provide communication between the swarm and the external facilities. The thicker dashed lines indicate the obstacles in the environment. The part of the environment with no visible obstacles represents a triangulation. The grey circles indicates the positions of the robots in the case if the environment had no obstacles, in which case an equilateral triangular grid would be preserved. Some of these positions are still possible, but not necessary, as the communication network can function without them. Some positions indicated by 'crossed' grey circles are simply impossible.

For the deployed ad hoc robot network, we discuss the routing protocol selection. Various routing protocols have been developed and proposed for ad hoc networks, which can be classified in reactive, proactive and hybrid protocols. Proactive protocols can offer low latencies as the routes are already available when needed. Destination-Sequenced

Distance-Vector Routing (DSDV) is a typical example for a proactive routing algorithm [10]. The routing protocol is suitable for a network whose topology is not changeable frequently. Consider the robots' moving mode and networks' deploying mode, in this paper, we adopt the DSDV as a routing protocol in ad hoc robot network.

III. MARKOV DECISION PROCESS FOR A FIREFIGHTER

The firefighting decision process can be modeled a discrete-time Markov decision process (MDP).The basic definition [11,12] of a discrete-time MDP contains 5 components, $(T, S, A_s, p_{tran}(s_i|s_j, a_{k_t}), r_k(s_j, a_{k_t}))$, described using a standard notation. $T = 1,2,...,k,...,N$ are the decision epochs, the set of points in time at which decisions are made (such as seconds or minutes in fire scene); S is the state space with finite states, the set of all possible values of dynamic information relevant to the decision process. We define S is a set of information (such as gas, temperature etc.) sensed by every robots. In other words, state $s_j \in S$ is information sensed by robot j; A_s is the action space, the set of possible actions that the firefighter can take at state s_j to get the exit. Where we suppose that $a_k \in A_s$ is an action at decision epoch k. The action a_k represents a action of the firefighter who currently is nearby robot j and is going to the neighbor location of robot i; $p_{tran}(s_i|s_j, a_k)$ are the transition probabilities, which are conditional transition probability on the current state s_j and action a_k at the current decision epoch k to the next state s_i; and $r_k(s_j, a_k)$ is the reward function, the immediate result of taking action a_k at state s_j and epoch k. As policy a is a sequence of the decision rules or actions to be used at each decision epoch and defined as $a = (a_1, a_2, ..., a_{N-1})$, the total reward of transformation from state s_j to s_i is $r(s_j, s_i) = \max_{a_k \in A_s} \{p_{tran}(s_i|s_j, a_k) r_k(s_j, a_k)\}$ .In next section, we will combine ad hoc robot network model with Markov decision model to discuss how a firefighter make decision for his or her evacuation in detail.

IV. A DECISION MAKING MODEL FOR A FIREFIGHTER'S EVACUATION

We know that evacuation is playing key role in search and rescue process. In this section, we discuss information fusion and a firefighter evacuation decision making based on dynamic triangular network. Because the deployment speed of dynamic triangular network may be slower than firefighter movement, while a firefighter is searching and rescuing, the robots can deploy the network by dynamic triangular network schema [8] as soon as possible. The evacuation decision making may be suitable for the situation when the firefighter has already finished rescuing task and ready to leave the fire scene. The authors in [13] informally clocked a guideline following exercise by experienced fire fighters: they progressed at crawling speed 12m in about one minute. The amount of oxygen contained in the breathing apparatus suffices for about 20 minutes. Given the crawling speed, they can proceed about 240m with a full tank. As they have to negotiate the 20 minutes of air between getting in and getting out, the maximum advance is only 120m. Due to the limited time for leave from the current location to the exit, the evacuation decision making is critical. In Fig. 2, a firefighter is going to leave the building from the exit after he or she has finished the rescuing task.

Due to the dynamics on fire scene, we know that the sensed information in ad hoc robot network is also dynamic variance. So in this paper, we adapt dynamic decision method, Markov decision process, to model the firefighter's decision making process for evacuation on fire scene. In firefighting decision making process, we know that the critical problem is how to define action space A_s, and evaluate the transition law $p_{tran}(s_i|s_j, a_k)$ in Markov decision process. In this section, we discuss those problems according to the triangular sensors situation in ad hoc robot network.

We only consider one-hop decision making problem, the two or more hop decision making problem can be operated similarly. For one-hop decision making process, the action space is $A_s = \{fl, fr, bl, br\}$. Where fl stands for the firefighter going *forward* to the *left* from one triangular vertex; fr stands for the firefighter going *forward* to the *right* from one triangular vertex; bl stands for the firefighter going *backward* to the *left* from one triangular vertex; br stands for the firefighter going *backward* to the *right* from one triangular vertex. We discuss how to get transition law $p_{tran}(s_i|s_j, a_k)$ for action a_k at decision epoch k. In general situation, we consider s_j has m one-hop neighbors. For triangular sensor robot network in Fig.2, m may be two, three or four. The firefighter currently is at the location of robot or sensor robot j. Consider a_k may be two, three or four probable actions related to robot j's neighbors.

For firefighter or robot j's neighbors only have two sensor robots in Fig.3, a sub graph of Fig.2. In Fig.3, robot j has two neighbors, robot i_1 and robot i_2. We use the temperature information $T(s_{i_1}), T(s_{i_2})$ sensed by robot i_1 and robot i_2 to define the transition law $p_{tran}(s_i|s_j, a_k)$ as fellow in Fig.3.

$$p_{tran}(s_{i_1}|s_j, a_k) = p_{tran}(s_{i_1}|s_j, a_k = fr)$$
$$= \frac{1/T(s_{i_1})}{1/T(s_{i_1}) + 1/T(s_{i_2})} = \frac{T(s_{i_2})}{T(s_{i_1}) + T(s_{i_2})}$$

$$p_{tran}(s_{i_2}|s_j,a_k)=p_{tran}(s_{i_2}|s_j,a_k=fl)$$
$$=\frac{1/T(s_{i_2})}{1/T(s_{i_1})+1/T(s_{i_2})}=\frac{T(s_{i_1})}{T(s_{i_1})+T(s_{i_2})}$$

For firefighter or robot j 's neighbors have three sensor robots in Fig.4, a sub graph of Fig.2. In Fig.4, robot j has three neighbors, robot i_1, robot i_2 and robot i_3. We use the temperature information $T(s_{i_1}),T(s_{i_2}),T(s_{i_3})$ and sensed by robot i_1, robot i_2 and robot i_3 to define the transition law $p_{tran}(s_i|s_j,a_k)$ as fellow in Fig.4

$$p_{tran}(s_{i_1}|s_j,a_k)=p_{tran}(s_{i_1}|s_j,a_k=fr)=\frac{1/T(s_{i_1})}{1/T(s_{i_1})+1/T(s_{i_2})+1/T(s_{i_3})}=$$
$$\frac{T(s_{i_2})T(s_{i_3})}{T(s_{i_2})T(s_{i_3})+T(s_{i_1})T(s_{i_3})+T(s_{i_1})T(s_{i_2})}$$

$$p_{tran}(s_{i_2}|s_j,a_k)=p_{tran}(s_{i_2}|s_j,a_k=fl)=\frac{1/T(s_{i_2})}{1/T(s_{i_1})+1/T(s_{i_2})+1/T(s_{i_3})}$$
$$=\frac{T(s_{i_1})T(s_{i_3})}{T(s_{i_2})T(s_{i_3})+T(s_{i_1})T(s_{i_3})+T(s_{i_1})T(s_{i_2})}$$

$$p_{tran}(s_{i_3}|s_j,a_k)=p_{tran}(s_{i_1}|s_j,a_k=br)=\frac{1/T(s_{i_3})}{1/T(s_{i_1})+1/T(s_{i_2})+1/T(s_{i_3})}$$
$$=\frac{T(s_{i_1})T(s_{i_2})}{T(s_{i_2})T(s_{i_3})+T(s_{i_1})T(s_{i_3})+T(s_{i_1})T(s_{i_2})}$$

Similarly, we can give transition law $p_{tran}(s_i|s_j,a_k)$ for firefighter or robot j 's neighbors have four sensor robots. By now, we can give transition law $p_{tran}(s_i|s_j,a_k)$ for a firefighter with all possible situations.

In section 3, we know that the reward of transformation from state s_j to s_i is $r(s_j,s_i)=\max_{a_k}\{p_{tran}(s_i|s_j,a_k)r_k(s_j,a_k)\}$. So, for calculate the reward of transformation from state s_j to s_i, we need to discuss the definition of $r_k(s_i,a_k)$. Consider it is difficult to position efficiently every sensor robots, so it is also difficult to calculate the distance between any two sensor robots. On fire scene, we need not to know the precise distance from the current location to the exit, we only need to know approximate distance in emergent situation. In triangular sensor robot network, if we know the communication hops (one hop means from one robot to its neighbor robot) from the current location to the exit, we could easily estimate the distance to the exit approximately. So, we can use the communication hops to definite $r_k(s_i,a_k)=\frac{h(s_{ini},s_{exit})}{h(s_j,s_{exit})}$ .Where s_{ini} is the firefighter's initial location state, s_{exit} is the firefighter's exit location state, s_i is the firefighter's current location state, s_j is a state transformed from s_i by take the action a_k. The function $h(x,y)$ means the communication hops from x location state to y location state.

Up to now, we can model the firefighter's decision problem as

$$r(s_{ini},s_{exit})=r(s_{ini},s_{i_1})+r(s_{i_1},s_{i_2})+...+r(s_{i_{N-1}},s_{i_N})+r(s_{i_N},s_{exit})$$
$$=\max_{a_1\in A_s}\{p_{tran}(s_{i_1}|s_{ini},a_1)r(s_{ini},a_1)\}+\max_{a_2\in A_s}\{p_{tran}(s_{i_2}|s_{i_1},a_2)r(s_{i_1},a_2)\}+...+$$
$$\max_{a_N\in A_s}\{p_{tran}(s_{i_N}|s_{i_{N-1}},a_N)r(s_{i_{N-1}},a_N)\}+\max_{a_{N+1}\in A_s}\{p_{tran}(s_{exit}|s_{i_N},a_{N+1})r(s_{i_N},a_{N+1})\}$$
$$=\max_a\sum_{k=0}^{N}r(s_{i_{k-1}},s_{i_k})$$

The firefighter's decision making process is to search policy $a=(a_1,a_2,...,a_{N+1})$, a sequence of actions at each decision epoch.

V. CONCLUSIONS

In this paper, we give a firefighter's evacuation decision making model to solve the dynamic decision making problem on fire scene. For simplifying decision or action space, we only discuss one hop communication situation. For two or more hops communication situation, the decision space may be enlarged with exponentially, decision making complexity may be increased, and decision making responding time may be slowdown. Although we only discuss evacuation for fire scene, the method could be applied in other similar disaster situation, such as mine rescues, battlefield searches, etc.

In this paper, by primary experiment, we find that the one hop by hop decision making method may also waste time and lose the opportunity for evacuation on the fire scene. We think that some times on explicit fire spreading situation, we may use two or more hops decision making model, some times on vague fire spreading situation, we may use one hop decision making model, and we are dealing with this problem.

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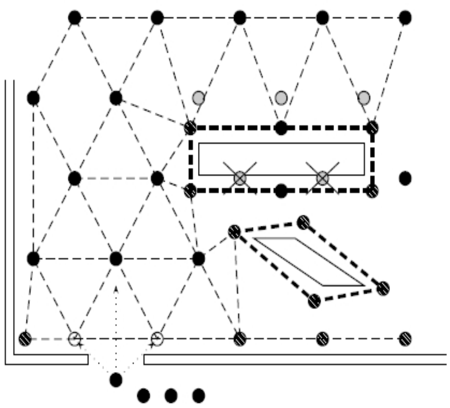

Fig. 1 Dynamic triangular network schema [8]

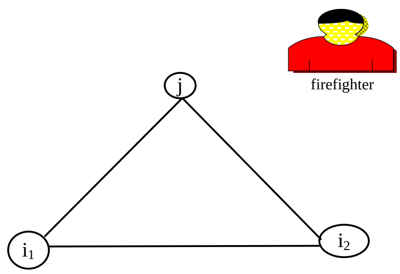

Fig. 3 Firefighter or robot *j* ’s neighbors only have two sensor robots

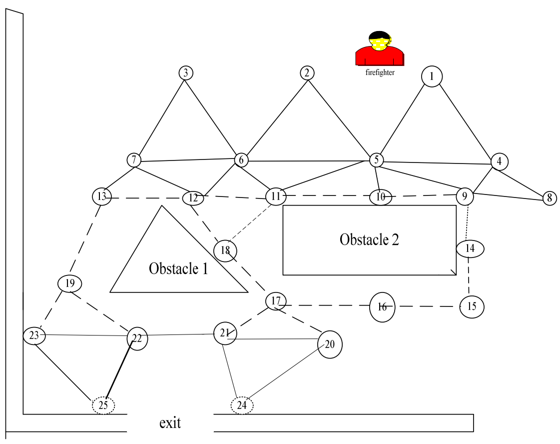

Fig. 2 Information Fusion and Escapable Graph [6]

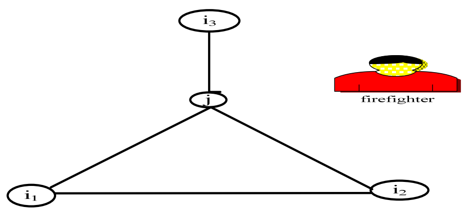

Fig. 4 Firefighter or robot *j* ’s neighbors have three sensor robots

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