Understanding Firefighters Behavior for Human-Robot Cooperation in Urban Fires

Micael S. Couceiro and Rui P. Rocha, *Member, IEEE*

***Abstract* — The most frequent incidents in urban areas are urban fires, requiring a prompt response. The use of mobile robots in urban search and rescue (*USAR*) scenarios, including urban fires, has been proposed to assist first responders, so as to take advantage of robots' expendability to reduce life endangerment and carry out more effectively the missions. Despite their recognized relevance, further research on the use of mobile robots in such scenarios is still needed to better assess the advantage of the cooperation between teams of robots and teams of humans in firefighting operations and in other USAR scenarios. In this short paper, we outline the key features of a firefighter behavior in response to an urban fire in a large basement garage. This behavioral model was assessed based on interviews with a Portuguese Fire Department, so as to highlight the importance of human-robot partnership in order to decrease the risk exposure of first responders and victims.**

I. INTRODUCTION

The top priority of any urban rescue team is to quickly locate and save human lives in eminent danger. It is essential to provide first responders with adequate tools and detailed information of the whereabouts of the rescue mission. Impelled by such motivation, many research teams have proposed advanced field technology to assist human agents in the "*theater of operations*". It is clear that assistive technology like Human-Machine Interfaces, ground exploration robots and advances in communication systems can make a difference in the field of operations.

In this work, we start exploiting the behavior of firemen teams undertaking an urban fire in a large basement garage. To that end, several important variables at stake are modeled.

III. MODELING THE CHOPIN USE CASE: FIREFIGHTERS' BEHAVIOR

The *CHOPIN* R&D project[1] aims at studying cooperative architectures in urban search-and-rescue (USAR) scenarios. One of these scenarios is a fire outbreak taking place in a large basement garage frequented by people and containing inflammable materials. The scenario is challenging due to the confined nature of the environment. As the fire evolves, it becomes rapidly filled with smoke, causing low visibility and an unbreathable and toxic atmosphere, which is hazardous for humans.

The proposed models for the most relevant features and behaviors in such conditions were retrieved from literature and adapted according to information collected in a set of interviews at the Coimbra Fire Department (*BSC*)[2].

The predictability of human actions is far from being estimated as each rescuer adapts to its own perception of the context [1]. This paper does not focus on general human behavior. It focuses, instead, on the action plan describing the procedures that firefighters have under *USAR* operations.

In average, only one or two teams enter the scenario to ensure the permanence of backup teams outside the imminent danger zone. Each rescue team advances in the scenario while maintaining a life safety rope linked to the exit to avoid getting lost in the catastrophe site. Due to the rapid evolution of an urban fire, the rescue operation does not take long. After a short period of time, the firefighters need to regroup to establish the means of action and proceed to the next firefighting phase. For that reason, the rescue phase typically lasts between 10 to 15 minutes. Nonetheless, for the sake of simplicity and due to the emphasis of the *CHOPIN* project, we will not consider any further than the search and rescue phases.

The motion of firefighter n may be described as:

$$m_i \frac{dv_i[t+1]}{dt} = m_i(v_n^0[t] - v_i[t])\tau - \alpha_W \nabla W - \alpha_T \nabla T, \qquad (1)$$

wherein m_n is the mass of firefighter n. The variables $v_n[t]$ and $v_n[t+1]$ are the velocities in the previous iteration and in the current iteration, respectively. τ is the stochastic inertial coefficient, which can be considered uniformly distributed between 0 and 0.9. The upper limit is defined in such a way that the previous velocity has a significant influence on the current velocity due to human dynamics. ∇W and ∇T are the gradient vectors of sensed obstacles and temperature, which are respectively affected by the parameters α_W and α_T that tune the sensitivity of victims to both constraints.

Firefighter agents typically have a temperature sensitivity of only 2 meters. This lower sensitivity to temperatures is explained by firefighting suits that handle temperatures of approximately $260°C$.

Also, as smoke and heat compels the firefighters to slowly follow the walls to avoid getting lost, they may have to crawl on the floor, thus reducing their speed even more. At best, they are able to achieve a velocity of $1\ m/s$ (slow walking speed). This is translated to a well-known task modeled in computer science and robotics named *wall following*.

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M. S. Couceiro and R. P. Rocha are with the Inst. of Systems and Robotics, Univ. of Coimbra, 3030-290 Coimbra, Portugal, e-mail: {micaelcouceiro, rprocha}@isr.uc.pt.

M. S. Couceiro is with Ingeniarius, Lda., 3050-381, Mealhada, Portugal, e-mail: micael@ingeniarius.pt.

[1] http://chopin.isr.uc.pt

[2] http://sapadoresdecoimbra.no.sapo.pt/

Each rescue team consists of two firefighters. To allow a straightforward implementation of the wall following behavior, while keeping a short distance between both agents, only one of them explicitly follows this behavior. Let us call it the *master agent*. The other one, the *slave agent*, follows a simple attractive mechanism towards the master agent, while keeping both repulsive forces from (1).

When exploring the scenario, firefighters' main concern is to find victims. While the master is trying to find the victim, the slave stays near the wall maintaining the life safety rope stretched between them. This ensures a safe return from the master carrying the victim to the slave. At that point, firefighters must drag the victim to a safer location before proceeding with the search.

II. FIREFIGHTING COOPERATIVE ROBOTICS

Robots can be an invaluable help if they are equipped with sensors that enable their navigation in a smoky atmosphere where human responders are highly hampered due to lack of visibility (*e.g.*, ultrasounds, thermal cameras, ultra-wide band radars). In this context, robots may provide a systematically updated map of the environment by means of multi-robot simultaneous location and mapping (*SLAM*) strategies (*e.g.*, [2]). Besides that, robots may also be used to maintain a communication network between first responders and the command center (*CC*). Last but not least, robots may assist in the acquisition of contextual information [3] that may be useful to firefighters, to successfully accomplish their mission in a shorter period of time with a decreased risk.

In the scope of the *CHOPIN* project, the authors previously presented a distributed collective robotic architecture in a *SaR* scenario [4]. The problem was divided into two phases matching the most critical phases of firefighting operation: *reconnaissance* and *rescuing*.

In the *reconnaissance* phase, a fleet of cooperative mobile robots aims to explore thoroughly the catastrophic scenario. Hence, the robotic team needs to be able to perform a cooperative exploration of the environment while participating in the search task, thus signalizing the presence of victims and possible evolution of the disaster so far (*e.g.*, mapping of temperature concentration in a firefighting operation).

The authors proposed a complete swarm robotic search solution denoted as Robotic Darwinian Particle Swarm Optimization (*RDPSO*) [5]. In brief, the *RDPSO* allows having multiple dynamic swarms, thus enabling a distributed approach since the network that may had been previously defined by the whole population of robots is divided into multiple smaller networks. The strategy of dividing the whole network into sub-networks enables a faster reconnaissance of the environment. In sum, the reconnaissance phase will correspond to exploring the scenario while robots perform cooperative *SLAM*. Hence, the objective function of the team is defined as a cost function in which robots need to minimize the map's entropy.

In the rescuing phase, the mobile robotic team should cover the whole scenario, identifying the location of any remaining victims and the possible evolution of the disaster. The problem resembles an inspection or patrolling mission, where the map is already available to the robots and important locations are defined. Therefore, the team of robots is expected to reorganize and visit all of these locations in an effective way and report new situations back to the *CC* such as undetected victims or new fire outbreaks.

For that phase, it was adopted a modified version of the State Exchange Bayesian Strategy (*SEBS*) for multi-robot patrolling [6]. Briefly, the idea is to have robots coordinating themselves in a distributed way, promoting efficiency in the patrolling mission. Robots decide their moves according to a *Gain* function that each robot expects to earn when moving to a location instead of another, and *State*, which guarantees the coordination between teammates and prevents them to visit the same locations. In this situation, robots identify important locations based on the reconnaissance phase, which may be temporary, and new locations may appear in the map during the rescuing phase, maintaining an updated list of locations that need to be visited.

III. CONCLUSION

This short paper gives a first step towards understanding firefighters' behavior so as to exploit human-robot teaming in *SaR* scenario. Based on the behavior of firemen, it was shown that human rescuers face extreme difficulties and timing constraints at distinct stages of the mission. By fostering cooperation with robot teams with specific capabilities, the potential to assist humans and gain effectiveness in this context should be proved. Therefore, in the future, simulation and field experiments are foreseen to verify and/or adjust the models used, as well as to present and validate real world solutions for human-robot cooperation teams in urban firefighting missions.

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