Integrating Affective Expressions into the Search and Rescue Context in order to Improve Non-Verbal Human-Robot Interaction

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ABSTRACT

Unexplained or ambiguous behaviours of rescue robots can lead to inefficient collaborations between humans and robots in robot-assisted search and rescue (SAR) teams. To date, rescue robots do not have the ability to interact with humans on a social level, which is believed to be an important ability that can improve the quality of interactions. In this project, we propose to bring affective robot expressions into search and rescue context to grant rescue robots with social capabilities. Affective expressions can be used as an additional complementary modality to convey information from rescue robots to field workers. We believe that supporting non-verbal communication in SAR teams with affective expressions will introduce a natural way to notify field workers about the rescue field and increase their situational awareness, as well as the effectiveness of interacting with the rescue robots. Additionally, affective search and rescue robots might be beneficial to keep victims calm until medical teams arrive and prevent/reduce shock.

CCS CONCEPTS

• **Human-centered computing** → **Interaction design**; *Empirical studies in HCI*;

KEYWORDS

human-robot interaction, search and rescue, affective expressions, human-computer interaction, multi-modal interaction, emotions, communication efficiency

ACM Reference Format:
Sami Alperen Akgun, Moojan Ghafurian, Mark Crowley, and Kerstin Dautenhahn. 2021. Integrating Affective Expressions into the Search and Rescue Context in order to Improve Non-Verbal Human-Robot Interaction. In . Workshop on Exploring Applications for Autonomous Non-Verbal Human-Robot Interactions at HRI 2021, March 8th 2021, Virtual, 4 pages.

1 INTRODUCTION AND RELATED WORK

The need for search and rescue operations has increased significantly due to natural or man-made emergency situations [40]. Robots have been employed in Search and Rescue (SAR) missions since their first appearance after the World Trade Center disaster [33]. The reason behind their wide usage is the potential dangers that SAR environments pose to human field workers [8, 22, 27], the limited number of trained rescue personnel [1], and the possibility of fast deployment of rescue robots [14].

Current rescue robots are not as intelligent as human rescue workers since they cannot operate fully autonomously in cluttered real-life environments without human help [12]. Hence, this leads to create an efficient collaboration between in human-robot search and rescue teams. However, despite all technical developments in field robotics, the interaction and communication between human and robot teammates pose the main problem in search and rescue robotics [8, 12]. Actions of rescue robots are not always clear to field workers due to lack of transparency in their actions and decision mechanisms [25]. In other words, field workers may not be able to understand what the rescue robot is doing, and why it is behaving in a particular way. For instance, while field workers are doing their tasks, they may realize that one of the rescue robots is always moving around a specific area, and it appears to be not searching other sections of the field. At that moment, this behaviour of the rescue robot may not be entirely clear to the field workers. To better understand the situation, field workers need need to stop the task and check different communication channels to understand the action of the robot. Some of these channels are voice, text, photos, videos or raw/processed sensory data like point clouds from LIDAR [10, 24]. While voice could be a fast way of conveying information, SAR fields are quite noisy in many cases and voice may not be an effective communication modality in all cases. Also, checking other channels (e.g., text, photos, etc.) can put an extra burden on field workers who are already under stress with the time-critical mission. In fact, this high stress level of rescue workers may lead to Post Traumatic Stress Syndrome (PTSD) [39]. It also reduces

the efficiency of the collaboration since field workers have to pause their task to understand rescue robot's actions/messages.

Therefore, there is a need for non-verbal and more intuitive interaction methods in human-robot rescue teams to overcome the above mentioned problem. Emotions and affective expressions may come into play to improve transparency of rescue robots. They can provide an intuitive and natural way for non-verbal communication since basic emotions are innate and universal [11, 16]. Intuitiveness of recognizing emotions may help reduce field workers' mental workload due to checking multi-modal communication channels (voice, text, video etc.) of rescue robots [45]. Furthermore, emotions could help with the robustness of communication in case one of the existing communication channels fails [21] or becomes ineffective, e.g. due to inadequacy of voice signals in noisy search and rescue fields [28].

In general, people expect/prefer robots to be social as stated by various researchers in the HRI community [15, 18, 26]. This can apply to rescue robots too. Indeed, as stated by Bethel and Murphy [6] and Fincannon et al. [17], people expect rescue robots to have social capabilities. Usage of emotions and affective expressions as a way of communication can give such capabilities to rescue robots.

The design of affective expressions has been studied extensively by the HRI community employing different modalities such as facial expressions [37], gaze [4], voice [38], gestures [44], head and body gestures [20], and non-anthropomorphic modalities like light [43] and sound [35], and they were combined in order to implement affective expressions on robots with various embodiment such as humanoids [9, 23], animal-like robots [32, 42], or machine-like robots [7, 36].

Yet, to the best of our knowledge, work done by Bethel and Murphy [5] has been the only attempt to bring affective expressions into field robotics, particularly search and rescue robotics. Bethel and Murphy [5] suggested design guidelines to use body movements, postures, orientation, color, and sound to implement non-facial and non-verbal affective expressions on the SAR robots: iRobot Packbot Scout and Inuktun Extreme-VGTV, and simulated a disaster site to conduct a user study and test the effectiveness of those suggested guidelines. While the guidelines were used to create a social robot (which was compared with a robot that did not have these capabilities), they did not implement different emotions for the robot [5].

Our focus in this paper is to discuss the importance and feasibility of using different emotions and affective expressions in search and rescue context rather than how to implement them. Our main goal is to understand if/how emotions can be used (along with existing communication modalities that rescue robots have) in order to convey information from rescue robots to field workers. We propose to use affective expressions as a complementary modality to increase efficiency of multi-modal human-robot communication in SAR teams. We believe this can help increase efficiency and transparency of SAR robots and improve human-robot interaction in SAR.

We emphasize the need for interdisciplinary research to make use of affective expressions in robot-assisted search and rescue. In this regard, we will discuss three studies (one published, two under review) on different steps of bringing affective expressions into search and rescue context. As a first step, we analyzed the relation between common scenarios that can happen during urban search and rescue missions and affective expressions [2]. In the second study, we included scenarios related to various types of search and rescue, and we proposed a method to automate the process of matching emotions with particular scenarios [3]. These two studies proved that bringing affective expressions into search and rescue context is possible. We also conducted another study to examine how recognition of possible implemented emotions are affected under limited visibility conditions that can happen during search and rescue operations [19].

The rest of the paper is organized as follows. The problem statement and challenges are presented in Section II. Section III explains the methodology and summarizes the results. Section IV describes limitations and future work. Lastly, Section V discusses contributions and impact of introducing affective expressions in the search and rescue context on non-verbal human-robot interaction in general and field robotics in particular.

2 PROBLEM STATEMENT AND CHALLENGES

A key problem in field robotics, particularly in search and rescue robotics, is the robots' lack of transparency of actions, which affects human-robot communication in robot-assisted search and rescue teams and reduces the efficiency of SAR task. Using affective expressions as a communication modality to complement the existing HRI channels in SAR can be effective in resolving this problem. However, there are multiple research questions that need to be addressed for successfully implementing affective communication in SAR robots:

- First, it should be decided how to use affective expressions. In other words, which affective expressions can be used in field robotics, and how these expressions can be integrated to field robots for communication? This would require an initial feasibility study, to ensure that there is consensus on which emotions SAR robots should show during SAR situations.
- If there is consensus, then it is important to study how affective expressions should be implemented after deciding which expression to use in each situation. Is it possible to find a natural way to design these expressions for field robots with different embodiments?
- As robots have different capabilities, they may be also limited in showing different affective expressions. What happens if the selected set of emotions change after the mappings are obtained? How can researchers make sure robustness of the SAR situation to emotion mapping against changes in the emotion set? (e.g., it may be beneficial to use a large set of emotions, but if a specific robot is capable of showing only a smaller set, it would be beneficial if there can be a way to change the mappings and adjust them to the new set).
- Although designing and implementing emotions for social robots is well-studied in HRI, there is not as much research on implementing emotions for appearance constrained robots like search and rescue robots. So, it is important to understand how to successfully create these emotions for appearance constrained robots, in order to increase the chance that

they will also be recognized under severe conditions of field robotics.
- Another important challenge after answering the above questions is how to evaluate the results of the HRI studies in an actual SAR situation in field robotics? Also, would field experiments be enough to guarantee ecological validity of the obtained results?

3 PREVIOUS AND ONGOING RESEARCH

To use affective expressions in SAR robots, first it is important to ask if people can understand the messages conveyed by a robot using affective expressions. Therefore, we started by asking if a robust mapping exists between emotions and a SAR robots' messages during Urban Search and Rescue (USAR) operations. In other words, if people agree on the affective expression that a robot should show in specific SAR situations. We conducted an online study where participants (112 in total) selected affective expression(s) (out of 11 options containing emotions and mood) to match sentences that cover situations happening during USAR operations. These sentences were presented to participants as messages that the robot wants to communicate, which were shown in two different wording styles. Results of this study demonstrated that there is consensus in the mapping between emotions and USAR related sentences, which is robust and independent of the wording of the sentences [2]. An example acquired mapping between a common scenario in USAR operation and suggested affective expressions is shown in Table 1 (see [2] for more information).

Table 1: An example mapping between a common situation happening during USAR with different wording style (Condition A and B) and affective expressions [2]. Stars show significance levels (*: $p < .001$, **: $p < .01$, and *: $p < .05$) comparing to selecting an emotion randomly.**

Sentence	Cond.	Suggested Mappings	
		First	Second
I think I heard someone is calling for help, we might have found a survivor.	A	**excited*****	**happy*****
Possible call for help detected.	B	**excited*****	**happy***

After confirming the feasibility of using emotions in USAR situations, it was important to understand how we can find mappings that can be used by multiple robots with different capabilities and range of emotional displays. For this purpose, additional situations related to different types of SAR were added to the previously mentioned ones and another online study with 223 participants was conducted [3]. A dimensional emotion model was employed. Through this study we proposed a method that enables us to dynamically change the mappings between situations and emotions. Other than the flexibility to use the mappings with different robots, it can be beneficial as the mappings to specific emotions may be subject to change over time as meaning of emotions and their relations with the context are not static [13, 30].

As discussed earlier, there are also other considerations for using emotions in SAR. For example, given that visibility is limited in multiple SAR situations, it is important to ask whether robots' emotions are recognizable under SAR conditions with limited visibility. To address this question, we have conducted two online studies and the results indicated that affective expressions of a robot shown through its body and head gestures can be recognizable under different visibility constraints [19], supporting our goal to use affective expressions to improve non-verbal human-robot interaction in robot-assisted search and rescue teams.

4 LIMITATIONS & FUTURE WORK

The main limitation of our work is related to conducting online experiments rather than realistic field experiments. However, this was not possible due to Covid-19. However, moving step by step and not starting directly by designing affective expressions on actual robots helped us to better understand and check the core idea of bringing affective expressions into the search and rescue field. In the future, our first step will be designing and implementing affective expressions on a rescue robot and thus closing the loop. We will investigate the impact of these affective expressions on the effectiveness of communication from SAR robots to rescue workers.

5 CONTRIBUTION AND IMPACT

We believe this research will highlight the need for more HRI research on search and rescue robotics. In this way, we can manage to overcome the previously identified bottleneck regarding inefficiency of human-robot interaction in SAR robotics [8, 12]. Initiating the usage of affective expressions in the SAR context as an additional communication modality can increase transparency of rescue robots' actions and be a solution to this bottleneck. Rescue robots equipped with affective expressions can also help keeping the victims calm and engaged until the rescue teams arrive [29, 41], and can reduce victims' stress levels and reduce/prevent shock [5]. Furthermore, using affective expressions as a way to convey information and complement multi-modal communication may inspire other application areas that involve human-robot teams such as firefighting, smart production, and healthcare.

Our research on employing dimensional emotion theories can also inform research related to sentiment analysis, since current work in this area has a limited literature about using specific emotion dimensions in specific contexts like search and rescue [31, 34]. Following such an approach can help researchers in finding emotional mappings faster and allow further analysis of data since this method does not depend on any specific emotion set, and can be used with any emotion set that may change, e.g., according to changing capabilities of robots. Furthermore, taking advantage of methods from both human-computer interaction and human-robot interaction may result in generalizability of the findings, so that they can be applicable to both social robots and socially intelligent agents.

The findings of the proposed study can inform design of SAR robots that can effectively communicate with humans in human-robot teams and increase efficiency of activities in SAR situations.

ACKNOWLEDGMENTS

This research was undertaken, in part, thanks to funding from the Canada 150 Research Chairs Program.

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