Modeling Human Behaviour in Emergency: A Research Agenda for the Creation of a Rescue Robot

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Abstract. The development of an artificial agent-driven rescue robot capable of interacting naturally with humans under urban emergency conditions brings out a number of issues that need to be addressed: among these are (i) providing a full description and understanding of the user’s perspective, and thus creating a reliable and functional user model, (ii) addressing the question of appearance, including the interface to be implemented, and (iii) evaluating the reliability and credibility of such a robot under, both group and individual panic reactions to stressful, extreme conditions. This article addresses these topics with a set of suggestions for future research in the field. In particular, we propose a research agenda focused on the appearance of a rescue agent, and its trustworthiness under extreme circumstances, together with suggestions for a set of experiments aimed at enlighten a user model of crowd and individual behaviour in emergency situations.

Keywords: Human behaviour in emergency, model of individual and group panic, adaptive rescue systems.

Introduction

When designing a specific research agenda for human-robot interaction under emergency conditions, a number of interesting questions related to social and psychological dynamics turn out to be relevant. Of these, the most important are those addressing a comprehensive user model, and the key factors related to appearance design and reliability. Despite the fact that the literature on rescue robots in urban scenarios is already well established (see e.g., [25], [41] for a review), a clear agenda for a robot capable of trustable human-machine interaction is, to date, an open challenge that poses several problems. In this article, we will review the literature and the experimental settings currently available in order to define a research agenda aiming to define a model of the human behaviour under conditions of urban emergency.
emergency, as well as at identifying the agent features that satisfy the requirements of credibility and trustability by a human individual or group under circumstances of panic.

The most relevant problems that need to be addressed for developing such a rescue robot are: (i) a full description and understanding of the user’s perspective that should bring to the definition of a reliable and functional user model; (ii) the question of appearance and design, including the interface to be implemented, and (iii) the issue of the reliability and credibility of such a robot under conditions of panic, both in terms of group and personal panic reactions to stressful and extreme conditions. The implementation of the robot and the communicative efficacy of the parsing model on the one hand, as well as the human online response to the robot on the other, will pose further challenges that will not be addressed here. We will rather address questions related to the definition of a user model that includes individual and crowd panic, as well as the design of trustable appearance features for the rescue robot. Since the disaster scenario is determinant for the specifications and appearance of the robot (see e.g. [25]; [41] for a review of the types of scenarios), we will focus here on a generically “ground”, “man-portable” [25: 1153] humanoid robot specifically designed for “urban search and rescue” [25: 1154], or the task of rescuing humans after a natural or manmade disaster such as an earthquake or a nuclear accident. Therefore, the user model should consider the human reactions to robotic aid in a hot zone, where humans cannot be employed. Special attention will be devoted to the psychological phenomena in play during disaster, such as individual and mass panic. Before addressing the problems involved in designing a robot that results psychologically trustable for subjects under stress condition, we nevertheless need to briefly address the general question of a User Model and its importance in the design and creation of a robot.

1. User Model: What It Is and Why It Is Important

Because the robot we want to implement is an adaptive systems programmed to respond to human behaviour by simulating typical human interactions, a comprehensive model is needed of the possible sets of “user” final conducts. This model is typically called the “user model” (see e.g., [3]). In addition, for the robot to work properly, it is also necessary to establish a full description of the robot itself (simulating proprioception), which is normally referred to as the “model of itself” [3].

In human-machine interaction, a user model is nothing more than what the system “knows” about the perspective and/or the expectations of the actual user. This knowledge normally includes both psychological data (developed through thorough psychological studies), and a user profile that gauges the preferences of a specific user or class of users by means of a monitoring system. The study of Blumer [4] on crowd behaviour supports the idea that, in a given situation, any performed human action is the result of a decision-making process, which is not random or even directly resulting from a stimulus-response relationship (i.e. a change in the environment). This decision making process consists of: a) perceive certain cues; b) interpret the situation and the risks; c) establish, on the perceived cues and the evaluation results what to do; d) perform the corresponding action. Even though influenced by certain
factors such as individual differences and interpretation of the situation and risks, this model of behaviour has proven to be general and it was exploited in several evacuation disasters [5] [22] [12]. Therefore, given the emergency situation, we may approximately assume that psychological behaviours are more likely to be stable for a single user and to function effectively as a paradigm for a wider set of users [46] and consider it a more reliable source for modeling the user’s perspective. In the case of evacuation robots, the user model needs to provide a comprehensive inventory of possible human (personal and group) reactions to unexpected stressful situations, as well as assessment algorithms of the degree of trust and credibility users might ascribe to a robot under such circumstances. There is an extensive literature aimed to predict the human behaviour in emergency situations, either taking into account the robot communication features or the prediction models (in particular, for prediction models, see the interesting review in [32] [36] as suggested by an unknown reviewer of this article). However, this research agenda aims at building a comprehensive user model focused on panic, so that the appearance of the robot takes into account the possible user’s reactions, and minimizes possible negative effects by means of a motivated design that reduces any impression of unreliability and/or distrust. For this reason, the user model of a rescue robot needs to account for a comprehensive set of human behavioural patterns.

Within the field of robotics and computer science, different applications (although not directly related to the evacuation issue) have been attempted, both in terms of a user model and in terms of the actual realization of the robot. One of the first user model can be seen in GRUNDY [26] that introduces and applies the idea of stereotypes to human-machine interaction. GRUNDY is programmed to recommend books to customers, and selects the most suitable title according to prototypes that are triggered by the user’s answers. The concept of prototype, which can be traced back to the idea of Script and Role in Computational Linguistics [37] might be useful to help specify a definite set of user models according to main psychological types. It is widely accepted, for instance, that the response behaviour of children interacting with humanoid differs – in terms of preferences for the appearance, behavioural response, and degree of cooperation – from the behaviour of adults under the same conditions [31] [48]. Such variables need to be included in the user model of any adaptive agent handling human emergency, including possible adjustments to the emotional state of the user. To this aim, Lisetti and Nasoz [18] have proposed an architecture designed to sense the user's emotional and affective states through the online processing and encoding of visual, kinaesthetic, and auditory input signals. In a successive study [47] they introduced biosensors in order to add physiological measures for a better encoding of emotional states. However, despite the interesting outcome of applied research focused on emotional adaptive systems, the online processing and encoding of large amounts of data poses several computational problems and may still not be effective for implementing a trustable and credible rescue robot. An efficient and computationally pre-determined user model is thus indispensable: such a model will be based on basic behavioural models extrapolated from the results of our experiments and will allow a certain degree of flexibility, which is essential for a trustworthy adaptive behaviour in the robot.
2. Building a Model of Panic: A Psychological Approach

A key factor when designing an evacuation robot is the capability of predicting the human (both individual and crowd) response to an artificial rescue agent under given environmental circumstances. With this in mind, it is important to implement a mathematical model. This model, however, should factor in social and behavioural components typically absent from previous proposals. As Santos and Aguirre [36] point out in their review, few artificial rescue agent models incorporate features of typical human social behaviour, and more importantly, no current model accounts for individual and crowd response to catastrophic circumstances. We propose to develop a model which accounts for these factors.

It is most likely to expect, under such conditions, a panic response, which brings to the fore a number of questions:

- Is it possible to model individual and crowd panic? How panic behaviour differ from typical social behaviour? Which features made the differences between them?
- Is it likely that humans under panic circumstances will accept help from a robot?
- Will a group of humans under panic conditions respond to an evacuation robot?
- Which elements of a human group under marked environmental circumstances will most probably respond positively to the help of a robot?
- What aspects shall we focus on in order to build a trustable and usable evacuation robot?

Despite the fact that the definition of panic is itself rather controversial [32], studies already carried out on the topic are diverse and refer to the basic social [47] psychological knowledge of crowd behaviour and crowd panic as opposed to individual responses (see e.g., [17] [44]). In addition, previous attempts to model panic behaviour in a mathematical way must be considered. These attempts deserve a certain attention since may be of great utility for defining the features and the functions of a rescue robot.

Cherif and Djedi [6], for example, provide an interesting model of crowd panic response that is focused on the assumption – mainly based on Allport’s [1] “individualistic” concept – that group dynamics – usually involving behavioural flow from groups to individuals – are disrupted during panic response to emergency: this would cause the break-up of the sense of group, with subsequent focus on the individual. The individual thus becomes the centre of the behavioural flow, while his conduct patterns are originated by other persons and reach crowd dimensions by emotional contagion [14].

Other interesting threads of research in the field focus on the observed convergence toward affiliative bonds during emergency and catastrophic events [20]. Mawson’s Social Attachment Model [20] claims in fact that mass panic is usually observed when two basic conditions are both fulfilled, namely, an imminent physical danger and the presence of strangers during the emergency. In this regard, the Entrapment Theory (see [23] [27] among others) maintains that the causes for mass
panic are mainly given by the coexistence of two environmental conditions, namely, imminent physical damage and a limited number of escape routes. It is interesting to note that, when the feeling that no escape from danger is possible, individual and crowd panic are not likely to be observed [23].

Reicher’s [29] Elaborated Social Identity Model of mass behaviour suggests, to the contrary, that a common identity emerges among individuals as a result of a shared danger, which might also explain the lack of mass panic under catastrophic conditions. The cognitive framework implied by the Elaborated Social Identity Model, and its cognate theory known as Self-Categorization Theory [43] was tested with actual survivors of disaster [7], who were contacted by means of an advert and interviewed. Although somewhat controversial because of the request to recall a stressful event long after its occurrence, on the one hand, and because of the methodology used for interviews (mainly focused on self-evaluations based on the memory of the stressful event), the experiments seem to show that mass panic is less frequent than normally claimed.

The relevant mathematical models of social behaviour are those related to Game Theory that can be summarized in the Prisoner’s Dilemma, a non-zero sum game developed by Flood and Dresher during the 1950s and reported by Tucker [42], which consists in two subjects who after being arrested by the police are kept separate for the interrogation. According to the game rules, prisoners know that, if both remain silent, they will only be sentenced to six months. The best strategy is thus cooperation, although psychological studies prove that subjects involved in the game usually betray each other [28].

Social Choice Theory [2] extends the principles of Game Theory and accepts the basic claim that negotiation does not always follow the traits of perfectly rational and linear judgment: cognitive, emotional, age, and gender biases (among others) have been found to influence decision making.

On the other hand, the Information Foraging Theory [26] for instance, in applying the principles assumed by anthropologists and ecologists for the basic mechanisms of food hunting (the Optimal Foraging Theory [19]) to the basic processes of information retrieval, is, an interesting starting point for the analysis of information retrieval under both normal and emergency conditions.

Individual choice in a potentially dangerous situation has been previously addressed by the mathematician Saaty, who proposed his Analytic Hierarchic Process technique [34]. This mathematical approach to individual decision making under adverse conditions is based on the fundamental distinction between individual-subjective evaluation of the situation and objective data.

Notwithstanding the interesting outcomes of mathematical models, though, none of the works reported above take into account the emotional implications of decision-making, adaptation, and responsive behaviour under emergency. In this regard, Social Psychology (see e.g. [11] [17]) has contributed extensively by providing concepts and theories explaining the basic principles of crowd phenomena. Le Bon [17], among others, tended to interpret the crowd as a unitary living organism provided with its own consciousness, mind, and morally responsive behaviour. Although this has been abandoned (see e.g., [1]), a description of crowd credulity on the one hand, and the phenomenon of the exaggeration of sentiments on the other will be of some interest to the aims of this study. Phenomena such as the contagion of emotion (see [13-15] for a
review), or the sympathetic induction of emotions as described in McDougall’s [21] work, are, in fact, key concepts for the analysis of the basic psychological mechanisms for interpreting and predicting crowd behaviour. Among the major issues, a particular focus can be placed on the shared group response caused by a shared environmental stimulus, the release of the shared experience given by the perception of its occurrence to others, and the resulting amplification of the overall emotional experience leading to instinctual group reaction. In this regard, Mintz’s [23] claim that emotional rise is not the cause of panic, which is instead caused by the unstable reward structure of the emergency situation, is particularly interesting for an interdisciplinary model of crowd response, although the experimental results confirming his theory are somewhat controversial and have been dismissed by several psychologists working in this field (see e.g. [14]).

Nevertheless, it is important to underline the fact that an optimal model of crowd and individual response to robots should account for all the above multidisciplinary aspects. The basic issue, when addressing the expected response to a robot from a group under emergency conditions, is in fact the need to develop an adequate mathematical, cognitive and behavioural model of crowd panic. For this purpose, a blend of both mathematical and social-psychological approaches may lead to a more precise behavioural model.

2.1. Building a Model of Panic: A Research Agenda

In spite of the fact that a model of crowd panic can only be obtained from the analysis of real panic behaviour during induction tests, such a research direction proves to be not applicable in concrete terms because of public security concerns. A set of tests and experiments aimed at evaluating data from individual panic behaviour can nevertheless be proposed.

The studies already conducted on the effect of a virtual crowd in human users [38] have a dual use in this project: on the one hand, these and similar studies can help to reach a trustable model of human response to evacuation robots; on the other hand, once the first prototype of the robot is achieved and needs to be tested, a virtual reality environment can also be employed for tests with possible final users.

Experiments in this direction should create basic controlled conditions of crowd panic by means of simulation, using currently commercially available 3D video games. All experimental sessions should be recorded by means of video cameras and eye trackers, in order to gauge information about the behavioural response to the agent.

A first experimental phase might consist of a test aimed at eliciting individual panic responses to be recorded with eye tracking (to record gaze, and thus attention fixation and gaze wandering as a symptom of distress) and video equipment, in a virtual environment. The videos will provide data for subsequent analysis of both verbal and nonverbal communication signals exploited in such situations. In particular, fluency data will be available as further evidence of the efficacy of the robot (see e.g. [45]), along with nonverbal indicators of panic, such as nervous ticks, and shaking over the time course of the robot-human interaction (see, e.g. [27]). Data thus acquired would constitute a database for an individual panic model: in this case, subjects suffering from panic disorder as well as normal participants might be needed.
in order to compare typical and anxious population responses. Situations where
participants find themselves locked in an elevator or in a small room due to the
malfuntioning of a door, while a fire alarm sounds in the building, might serve for
these purposes.
A parallel experimental set might involve small group interaction in a virtual
emergency environment involving room escape in a given amount of time. The
responsive behaviour of groups of 3-5 subjects to an emergency scenario should be
recorded under three different circumstances:

- Groups of friends and acquaintances under emergency conditions;
- Family groups under emergency conditions;
- Groups of strangers under emergency conditions.

The different social and behavioural patterns recorded in the three conditions may
help design an accurate and possibly exhaustive model of panic group response,
paying attention to family relationships, and affective tie phenomena. It is expected,
for instance, that members of a family group might be more likely to cooperate with
one another while groups of strangers might be more subject to panic, here intended
as irrational response in otherwise normal subjects under the conditions proposed by
the Entrapment Theory [23] [27]. It is also plausible to expect that the response of
anxious subjects will be more dramatic. A further step will include psychological
behaviour testing of individuals interacting with the robot prototype under controlled
panic simulations.

The data acquired from these experimental sets will provide human behavioural
features that must be accounted for create a trustable mathematical model of
individual and mass behaviour in emergency conditions provide a fully detailed
model of the possible human response to the evacuation robot itself.

3. Appearance Design

Several studies have shown the importance of robot appearance to the final user,
especially under circumstances of emergency, where the psychological
trustworthiness of the agent is determinant. In general, as far as the appearance design
of a humanoid robot is concerned, there is evidence [24] that the more it resembles
human traits, the more it is considered to be familiar, reassuring, and pleasant to deal
with. Nevertheless, a critical threshold (the “uncanny valley” [24]) is reached when
the robot or humanoid reaches an excessive human-like appearance: the violation of
this threshold causes an instinctive rejection of the robot by the intended final user, as
well as feelings of repulsion, revulsion, and, in some cases, fear. While this idea has
been called into question [10] and may be of less importance for the appearance of a
research or consumer robot, evacuation robots need to interact with humans under
strong emotional stress, and thus its exterior appearance plays a significant role.

For this reason, the robot exterior appearance will be tested in a two-fold enquiry:
the first phase of the enquiry will recruit potential final users in order to allow for a
balanced sample according to sex, age, and education. A detailed questionnaire that
addresses the expectations concerning the appearance of an evacuation robot will be
distributed. Subsequently, the data collected will be analyzed and the robot design will follow accordingly. Different responses are expected from different segments of the population (e.g., children versus adults), with a likely preference for non-humanoid robots.

Nevertheless, it is possible to pre-establish the size and mechanical abilities of the robot in order to accommodate the need for efficient performance in potentially dangerous environments, including basic motor operations, such as the following:

- precision grip/grabbing
- pulling and throwing or letting go
- walking
- climbing stairs
- (possibly) crawling in order to reach difficult areas such as underground niches resulting from an earth-quake

Moreover, for safety and portability reasons, the robot should not exceed 120 centimeters and should be equipped with contact and impedance sensors, movable joints for a more flexible kinesics, and movable eyes for better recognition of their human counterparts and a better appreciation of the environment.

Some robots presented in literature already are provided with the aforementioned features. In particular, ASIMO [16] [35] is probably the only robot capable of climbing stairs, and iCub [9] is equipped with an accurate precision grip, and in general some other are able of walking, bending, grabbing, pulling, and letting go (see [36] for a review). However, there not, to data, a robot that is equipped with all the features needed for a rescue robot, and therefore it will be necessary to build a prototype with all the previously described specifications.

A further step will require implementing the robot by also programming a parser for both nonverbal behaviour and speech, together with a system for the online response of the agent under the conditions already specified in these pages. This will also imply addressing problems related to emotional intelligence (see, among other studies, [39] for emotional intelligence in robot-to-robot cooperation, [40] for emotional intelligence in human-robot interaction, and [45] for the perception of emotions in human speech). Of course, the structure of the program will include the data available from the tests already conducted in order to provide a comprehensive User Model focused on the psychological side of the prospective final users.

3.1. Evaluation of Acceptability: Possible Tests

Usability and trustability tests should be structured in three main stages: during the first stage, a questionnaire focused on the expectations of the prospective final users can be used. Groups of informants with diverse demographical features, such as educational background, age, geographic area, different levels of acquaintance with robotics and information technologies, and sex, should be asked to provide as much details as possible concerning their expectations for the appearance of a robot for rescue tasks.

During the second stage, another comparable set of informants should be asked to interact with the prototype robot under controlled panic conditions. The panic
condition and the robot appearance will be simulated by means of an adaptive computer program that will be similar to a 3D videogame both in terms of graphics and environmental and/or crowd response modeling. The response of subjects to two robots should be tested: the first humanoid robot will show a state of the art appearance and will not exceed in human-like features, while the second will reproduce human features in a more exact fashion. Parameters such as voice quality and sizes should also be tested. During this phase, the behaviour of the participants should be recorded by means of eye tracking and video recording of the sessions. Individual response to virtual crowd panic should also be tested. After each session of virtual interaction, each informant should be asked to answer a questionnaire on the trustability and usability of each robot.

Finally, a third phase could involve interaction with a prototype obtained from the preferences and user models identified by the two previous phases. This phase might involve recording sessions where each participant is asked to interact with the robot under controlled conditions of crisis, such as an earthquake emergency simulation, while an eye tracker records his/her eye movements. The eye tracker will here measure both gaze fixation and gaze aversion rates, so as to assess whether the robot reduces distress (lower gaze aversion and random eye movement rates) and inspires trustability (higher gaze fixation rates). Similarly, a measure of speech fluency in the subjects could serve as a further indicator of reduced distress after interaction with the robot. A further experimental session would involve the use of the robot under circumstances of controlled catastrophic events, such as a simulated earthquake, and/or fire evacuations in schools or public buildings. In order to avoid a social desirability bias [8], recordings will also be done during the second step of the evaluation process.

Once the basic tests of the general appearance of the robot are concluded, further tests should include a thorough evaluation of the usability of the prototype, focusing on the following issues:

- Voice quality (see e.g. [33] for the importance of a trustable voice for the general trustability of an agent to the final user);
- Behavioural effectiveness and trustability for detecting a “natural” synchronization between gesture, expressions, and speech (see e.g. [33] for the trustability of an agent);
- Overall appearance efficacy under the circumstances of individual and crowd panic already modeled with the data available from studies on mass panic (see section 2).

Finally, a defined appearance and a set of desirable behaviours will be selected and implemented. The final results should be tested again with another sample of potential final users.
4. Conclusions

A crucial issue when designing an evacuation robot is the capability to anticipate the human (both individual and crowd) response to the robot. The question of modeling such responses requires a clear model of typical responses to artificial agents, from which to broaden the model to accommodate the emergency environmental circumstances.

Studies already carried out are diverse, and often refer to basic social psychological knowledge of crowd behaviour and crowd panic as opposed to individual behaviour under emergency circumstances. Nevertheless, an optimal model of crowd and individual response to a rescue robot should be developed accounting also of cognitive and behavioural features of crowd panic. A definite set of experiments aimed at evaluating data from individual panic behaviour is thus proposed in these pages. In doing so, particular attention is given to the robot external appearance in human-machine interaction, which is a determinant factor for the usability and trustworthiness of these artificial agents. Finally, it is also suggested here that, in designing possible experiments, the variable responses of sociologically different individuals (such as children versus adults), in terms of robot appearance preference, overall behavioural response, and degree of cooperation should be taken into account.

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References


