Affective Collaborative Robots for Safety & Crisis Management in the Field

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ABSTRACT

The lack of human-robot collaboration currently presents a bottleneck to widespread use of robots in urban search & rescue (USAR) missions. The paper argues that an important aspect of realizing human-robot collaboration is collaborative control, and the recognition and expression of affect. Affective collaborative robots can enhance joint human-robot performance by adapting the robot's (social) role and interaction to the user's affective state and the context. Current USAR robots lack these capabilities. This paper presents theory, application domains, and requirements for affective collaborative robots based on the current state of the art. With methods from cognitive architectures, affective computing, and human-robot interaction, three core functions of affective collaborative robots can be realized: sliding autonomy, affective communication, and adaptive attitude. These robot functions can substantially enhance the efficiency and effectiveness of rescue workers and meanwhile reduce their cognitive workload. Furthermore, robots with such functions can approach civilians in the field appropriately.

Keywords

Human-robot interaction; affective computing; collaboration and decision processes

INTRODUCTION

Do we really need to bother with an affective robot that can act on the emotions of the user? Why should a rescue robot have to deal with emotions? The answer is relatively simple. In Urban Search and Rescue (USAR) stressful situations often occurs and stress has a substantial effect on rescue workers' performance and the behavior of other humans in the field (e.g. victims or passers-by). The lack of human-robot collaboration, in which the robot's behavior takes account of human emotions, currently presents a major bottleneck to widespread deployment of robots in missions set in environments that may be too hazardous or inaccessible for rescue workers (Bruemmer *et al.* 2003; Murphy 2004), or where robots can partner with humans to augment their capabilities (Fong *et al.* 2001; Sierhuis *et al.* 2003). Collaboration with the robot can decrease the cognitive workload and thereby enhance the performance of the user. Furthermore collaboration entails a higher degree of autonomy for the robot, raising its role from being a tele-operated machine to an embodied social actor that can move and act rather autonomously (Reeves & Nass 1996). This is where the need for an affective collaborative robot comes in. For a robot to be and remain an effective collaborator in safety and crisis management scenarios, it needs to be able to adapt its behavior on the basis of how it understands humans to affectively appraise a situation. Only this way, the robot will be able to help maintain optimal human performance under the cognitive load that stressful situations can present.

This means that for effective collaboration there is a need for collaborative control, affective communication between human and robot, and an adaptive attitude of the robot. For collaborative control and affective communication there are already solutions that do not work perfectly, but will probably work sufficiently in a limited context such as USAR. Furthermore, Breazeal & Scassellati (2000) discuss initial experiments with endowing a social robot with the ability to adapt its affective attitude during interaction. The adaptive attitude can enhance the joint human-robot performance by adaptation of the interaction to both the affective state of the user, and to the social relation between robot and user.

In this paper we argue the need for an *affective collaborative robot* in which models and methods from cognitive architectures, affective computing, and human-robot interaction meet. First we provide a scenario to give an application example, and then we provide a background to support the need for affectiveness in a robot. From the identified need for affective collaborative robots we induce core functions from which we distill requirements. We end with possible metrics to measure the performance of human-robot interaction and a conclusion.

SCENARIO

Space, military, medical, and safety and crisis management are all domains with unknown, hazardous, and dynamic environments where stress is a prevalent emotion and where affective collaborative robots are essential. Adaptation of the robot's interaction to both the affective state of the user and the social relation between robot and user can improve the effectiveness and efficiency of the astronauts, soldiers, medical personal, and rescue workers, and reduce the cognitive workload. In the space domain, NASA is developing a robot with dexterous abilities, the Robonaut (Ambrose *et al.* 2000). A Robonaut will serve as an astronaut's assistant during repairment procedures in a space shuttle or the International Space Station and space walks. Other "space robots" such as a rover could also collaborate with astronauts during exploration walks on planetary surfaces (Hirsh *et al.* 2006; Fong *et al.* 2006). In the military and medical domain, affective collaborative robots could be used for assisting soldiers (Rani 2003) or for medical help in the field (Yamauchi *et al.* 2004), respectively.

Assisting rescue workers in the search for victims is the main purpose of robots during rescue missions. The World Trade Center (WTC) disaster was the first time robots were employed for searching victims in the rubble (Murphy 2004). At the WTC disaster no surviving victims were found, but when surviving victims are found robots should not scare them and possibly give them medical and psychological support. The robots should also collaborate with the rescue workers (Murphy 2004). Figure 0 shows a scenario of how an affective collaborative robot could be used in USAR. The robot and operator have collaborative control; the operator takes over the control to get the robot unstuck. The robot also uses affective communication to make appropriate comments. Furthermore, the robot attunes its interaction to both the stress level of a rescue worker and the social role it has with respect to the victim, rescue worker, operator, and structural specialist.

> An earthquake has occurred. Many citizens were present in the buildings. Rescue teams with robots are arriving to search for victims. The first 48 hours are crucial and therefore it is necessary to have a good plan. In the mission control center a plan is drawn up and communicated to the human-robot teams. The robots start searching autonomously for victims in the rubble; one of them encounters a citizen that is desperately seeking for his wife. The robot notices the stress and that the man is not a rescue worker. The communication of the robot with the man is adapted to these observations. It tries to comfort the man and assures him that it is better he waits for his wife outside the disaster area, because of the danger of aftershocks. It can convince the man and after he has left it sends a message with a picture of the man to the PDA of one of the relief workers so that the relief worker can take care of him.
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> Meanwhile another robot got stuck and has sent a voice message to the PDA of its operator. The operator examines the 3D presentation of the situation of the robot and sees that robot can move a rock in front of it into a trench at the left. The operator then takes manual control of the robot and lets it maneuver the rock into the trench. Through this action the robot has learned to get unstuck in a similar situation as where it was, the next time it will be able to get unstuck itself. After it gets unstuck it goes further into the cavity it is exploring and notices the heat and CO_2 emission that are indicative for a human being. It starts talking to the victim but gets no reaction. The robot contacts the nearest rescue worker, which is not already busy with excavating a victim, to ask him for advice. The rescue worker is under stress, but the robot can give him the information in small chunks so he can think clearly and gives the robot the advice to pinch the victim. The robot pinches the victim and elicits a reaction. Now it knows that the victim is alive it starts talking to him in a comforting way and stays with him. It also sends a text message to a structural specialist to inform him where the victim lies. The specialist investigates the information and decides that at the moment, because of the high probability of aftershocks, it is too dangerous to salvage the victim. He informs the robot about this so it knows that it has to stay there for a while. This means that this robot is no longer available for exploration of the area. The mission control center is informed and together with the human-robot teams they form a new strategy.

Figure 0 Scenario

BACKGROUND

In this section we will show why there is a need for affective collaborative robots in safety and crisis management. To do so we will show how much influence stress has on the cognitive processes, how adaptive interfaces can influence the impact of stress, and how social robots can be used as adaptive interface.

Influence of stress on cognitive processes

In cognitive science emotions were discarded for a long time (Zajonc 1980), but research in psychology and neuroscience has identified the crucial role emotion has in decision-making and social interaction. Now it is widely accepted that cognitive processes are closely related to emotions. Emotions are shown to have both positive and negative effects on cognitive processes (Al'Absi *et al.* 2002; Damasio 1995; Sorg & Whitney 1992). Both people with lesions in their emotional system (i.e. "pure rational human beings", see (Damasio 1995), and people with high emotional responses show impaired decision making (Al'Absi, Hugdahl, & Lovallo 2002; Sorg & Whitney 1992). As shown by Sorg and Whitney (1992) and Al'Absi, et al. (2002), stress impairs the working memory. Affective states influence both low-level and higher-level perceptual, cognitive, and motor processes. Affective states can help activate or inhibit particular actions, and perception or processing of specific stimuli. In this way the mental model of the user is influenced by his/her affective state and experimental research has shown that the mental model plays a critical role in decision making (Hudlicka & McNeese 2001). Anxious people have a negative mental model of the world and research shows that they have a bias for negative interpretation of events and items (Mathews & Macleod 1994).

Adaptive interfaces

In the research area of affective computing the ability to recognize emotions and express emotions is implemented in technology (Picard 1997). By adapting a user interface to the affective state of the user, negative effects of stress could be diminished and the performance of the user could be improved (Hudlicka & McNeese 2001). The primary challenges of such a user interface are: Correct assessment of the user's affective state, prediction of the influence of the affective state on the performance, identification of the right approach to compensate for potential biases due to the affective state, adaptation of the affective interface according the affective state of the user (Hudlicka & McNeese 2001). The interface can for example notice that the user has a high stress level, predict from this observation that the working memory of the user will be impaired, identify that a shorter message could decrease the load on the working memory, and provide a shorter message to the user.

Social robotics

Robots are already used in USAR and therefore are a good platform for adaptive interfaces. Among others Fong, Nourbakhsh, and Dautenhahn (2003) point out that robots are perceived as social actors (Reeves & Nass 1996). A robot with an adaptive interface could, because it is more perceived as a social actor, have more influence on the stress level of the user than an adaptive interface (be it a text interface or a virtual agent) on for instance a PDA. Bartneck and Forlizzi (2004) propose the following definition of a social robot: "A social robot is an autonomous robot that interacts and communicates with humans by following the social rules attached to its role." The definition emphasizes the importance of roles in human-robot interaction (HRI). Roles are essential for social interaction and integration in human social systems. In current research with social robots, the robots have one role and one way of interaction; most research is done in the area of emotional expressions and imitation, not in emotion recognition and alignment.

AFFECTIVE COLLABORATION

Affective collaborative robots are needed in USAR, because they decrease the cognitive workload by moving and acting autonomously, and communicating in a human-like way in a stressful situation. Widespread deployment of robots in USAR, space, and military (Bruemmer, Marble, Dudenhoeffer, Anderson, & McKay 2003; Murphy 2004; Fong, Thorpe, & Baur 2001; Sierhuis, Bradshaw, Acquisti, van Hoof, Jeffers, & Uszok 2003) has been hold back by a lack of human-robot collaboration. In USAR, robots with an affective interface can be used for exploration of the disaster area. They can collaborate with users by using affective communication and adapting their interaction to both the stress level of the user and the social relation between the user and the robot, the cognitive workload can be decreased by correct adaptation. For the collaboration to be effective we identified three functions the robot should have: the control of the robot should be *collaborative*, the communication should be *affective*, and the robot should have an *adaptive attitude*. First of all collaborative control is necessary for collaboration. Sliding autonomy incorporates all intermediate levels of autonomy between tele-operation and full autonomy (Bruemmer *et al.* 2005;

Wegner & Anderson 2006; Trafton *et al.* 2006). The robot can do tasks autonomously, but can also ask for help and be tele-operated if necessary. A higher degree of autonomy for the robot evokes certain expectations about its social skills following Reeves and Nass (1996). Because a robot in USAR should be easily used by a wide range of people, affective communication in the context is important (Fong *et al.* 2003). For affective communication the robot should understand the utterances of the user and be able to react on them. Furthermore, the robot should be affective. With affective we mean that the robot's behavior is influenced by (emotional) appraisal of the emotional status of the user. Finally, the robot needs an adaptive attitude to be able to collaborate with both users experiencing different stress levels and with a wide range of users.

Requirements for affective collaborative robots

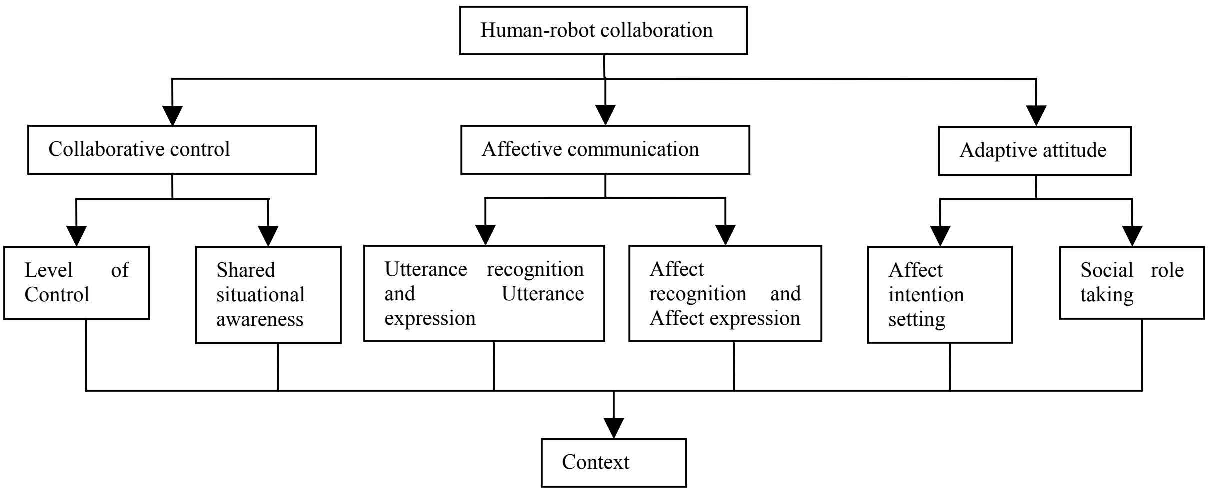

Figure 1 Requirements

From the three identified functions for an affective collaborative robot; collaborative control, affective communication, and adaptive attitude (Figure 1) we distilled eight requirements that each can be implemented in different ways.

Collaborative control

For collaborative control there is a need for adaptation of level of control both by the user and the robot. This level of control should be clear to the user. The robot could for instance, when it is stuck, put the complete control in the hands of the user. The user could also decide to give the robot more or less autonomy; he/she could do this for instance by a slider control on a PDA, or by a command that could be given to the robot.

Furthermore, the less control the robot operator has on the robot, the more important a shared understanding of the environment and tasks (Endsley 1995) is in order to understand each others' intentions (Dennett 1987). For collaborative control both the user and the robot need information about each others situation. The user can acquire information about the location of the robot by information about the general situation, by communication with the robot about its situation, by streaming video of the robot's location, and by a three-dimensional (3D) display wherein the sensor information of the robot is processed (Bruemmer, Few, Boring, Marble, Walton, & Nielsen 2005).

Affective communication

The robot needs to recognize and understand utterances and affect, and have the ability to express them, for affective communication. Teams of only humans communicate with each other using certain protocols. If the team is extended with robots, it should be possible to address the robots in the same way humans are addressed (Hirsh, Graham, Tyree, Sierhuis, & Clancey 2006). The cognitive workload of users can be reduced when the communication with the robot team members is similar to the communication with the human team members, otherwise the cognitive workload will increase. To accomplish a decrease of the cognitive workload, the robot should have the ability to recognize and understand speech and text utterances of the user. Speech recognition and understanding is very hard, because the punctuation and spacing between words is not evident. Fortunately the recognition rate can be improved much when the current context and perspective of the user is taken into account to disambiguate words and sentences (Trafton *et al.* 2005; Kruijff *et al.* 2006). To accomplish a similar communication between human and robot as between humans, the robot needs besides recognition and understanding of utterances also the ability to express utterances. Independent of the form of interaction, speech or text, the robot needs to have the ability to construct sentences that fit the utterances of the user and the context. If the robot uses speech for its utterances it needs speech production software to produce this speech.

For fluent communication the robot should be affective. Otherwise the robot will react inappropriately and unexpectedly to affective states of the user and people will not want to collaborate with it (Trafton, Schultz, Cassimatis, Hiatt, Perzanowski, Brock, Bugajska, & Adams 2006). If the robot is affective, people will feel competent when using the robot (Reeves & Nass 1996). To be affective the robot should have the ability to recognize and express affective states.

People recognize each others emotions by interpreting the facial expressions, gestures, posture, tone of voice, and context. A robot can analyze these external signs and can further use sensors to measure physiological signals. Notwithstanding all these measures computers/robots still have much difficulty to recognize emotions. Emotions can be classified pretty well when using a confined number of possible emotions. But the expression of emotions differs much between people and there are many different gradations of every emotion. The gradations of emotions can be represented in a circumplex model, where the horizontal axis represents the valence and the vertical axis represents the arousal (Posner *et al.* 2005). The classification of the emotions by valence and arousal is proposed by Lang (1995). For safety and crisis management fields such as USAR, we probably do not have to take the whole circumplex into account, this because we will have a standard interaction style that changes with different users and different stress levels. A high stress level can be inferred from negative valence and high arousal.

Stress is the emotion that will be present relatively often in USAR. Stress from rescue workers, stress from victims, and stress from other citizens. Metaxas et al. (2004) describe a method to recognize stress from the face. They use Hidden Markov Models for this purpose. But recognition from the face can be very hard in the field. Besides that the light conditions are varying all the time, the rescue worker should wear a camera that keeps track of its emotions all the time, this is very intrusive. Another option is to recognize stress from the voice (Pentland 2005), but to be dependable the voice has to be monitored over a longer period of time. This is not desirable during a disaster response. Rani, Sarkar, and Smith (2003) use cardiac response, electrodermal response and electromyographic response to detect anxiety levels. These responses qualify anxiety pretty well, although this is not yet tested when the person is physically active and physically activeness would probably influence the measures. Furthermore, it is not suitable for citizens to use, while they will not wear the measuring devices that are needed. For the rescue workers this will be no problem. A solution could be to treat all citizens in an extreme disaster environment as having stress and to adapt this preliminary conclusion to emotions expressed by the citizen by voice or face (captured by the robots and/or rescue workers). The physiological signals from the rescue workers can be measured to determine if they are stressed. For more disambiguation of the affective state of the user the context can be taken into account (Li & Ji 2005).

After the affective state of the user is recognized the robot has to appraise this state and react accordingly on it. Affect expression can be done in several ways; (1) by showing emotions such as happy, sad, anger, etc, (2) by body movements such as, gestures, and posture, (3) by showing certain behavior such as, gazing, and distance to the user, (4) and by changing the tone of voice (Schröder 2006).

Adaptive attitude

The ability to recognize and show adaptive behavior is not enough to make a robot affective. It should foremost adapt its attitude to the current context. For adaptive attitude the robot should be able to adapt to the affective state of the user and to adapt to the social role it has in relation with the user. To adapt to the different stress levels of users the robot should adapt its utterances and affect expression to the recognized affective state of the user. The robot can adapt its affect expression to the affective state of the user. A victim for instance could need emotional support, the interaction is then adapted to the social role the robot fulfills in relation to the victim and the affective state of the user. Evidence suggests that emotional support can make people physically and emotionally healthier (Sarason *et al.* 1997; Cunningham & Barbee 2000). In MacGeorge et al. (2004) it is shown that both men and women appreciate two support strategies most, advice and sympathy. Macgeorge et al. (2004) also show that people do appreciate highly person-centered comforting messages, wherein the feelings of the person are explicitly recognized and legitimized and the person is assisted to see those feelings in a broader context, most. When a robot could give the above mentioned two kinds of support in a highly person-centered way, the victim will probably appreciate its help. We have to say that this method probably works for western people, but that for example Asians do not appreciate highly person-centered messages (Mortenson *et al.* 2006).

Adaptation to the affective state of the user can mean a social role change of the robot. Role changes are also necessary to collaborate with a wide range of users. The robot can change its role by adapting its utterances and affect expression to the user. An affective collaborative robot can take different roles in different situations. When collaborating with the operator, it will probably take the role of subordinate or peer; while when it talks to a victim, it will take the role of rescue worker. When a user is stressed the role of the robot could change, for example from peer to superior. To take on these different roles, the robot should have an understanding of the user and context, and an understanding about how decisions are reached. By adapting its role to the user the robot will be perceived as affective.

Context

The three previous functions all lead to several requirements: ability to change level of control, shared situational awareness, utterance recognition, utterance expression, affect recognition, affect expression, affect intention setting, and social role taking. Furthermore, for all three core functions the robot needs *context* awareness. Robots are in contrast to affective interfaces of computers mobile so the own context can differ from the context of the user. An affective robot should therefore not only have situational awareness (Endsley 1995) about its own situation, but also about the situation of the user. The current context is of influence on how the situation, utterances, affective states, and roles are interpreted. Furthermore, the current context is of influence on how the robot should react on the situation, utterances, affective states, and roles. The current context is comprised of three aspects that overlap each-other: user, situation, and knowledge (Zipf & Jöst 2005).

- User: The robot can develop a model about the user by taking into account the user's situation, the interaction history, and a user model. For rescue workers there will probably be a user model available for the robot which it can adapt to, for citizens the robot can develop a user model by using interaction with the citizen as information for the user model. The user information is information about his/her position, affective state, physiology, and social role. The robot can acquire this information for rescue workers by knowledge about the general situation and sensors on the rescue workers. For victims assumptions must be made about their affective state, physiology, and social role. Information about its own situation the robot can acquire by different sensors such as cameras, radar, GPS etc.
- Situation: The situation is comprised in USAR of the general situation, the user situation, and the robot's situation. Situational awareness (SA) is defined by Endsley (1995) as comprised of three levels: Perception of the elements in the environment, comprehension of those elements, and use of this comprehension to predict future states. Both the humans and the robots should have situation awareness. A robot can perceive its environment by different sensors and with e.g. visual and spatial cognition it can comprehend the elements and predict future states. A robot can for example sense if an operator is doing something, the robot then comprehends that the operator is busy, and can adapt the message it sends to the situation. The general situation in USAR is the disaster area for which the robot needs the same information as the other team members. The robot needs to know where the team members are and what their roles are; furthermore it is important to know where possible roads, and hazardous materials are.
- Knowledge: Knowledge about important skills will initially be programmed into the robot. Such as good strategies for path planning and cognitive models of decision processes. This knowledge should be adaptable and expandable when the robot encounters new situations.

We described how the requirements for an affective collaborative robot could be implemented, but there is also the need for metrics that can measure if the requirements improve the performance of human-robot teams in USAR.

METRICS

We intend to improve the performance of USAR-teams by human-robot collaboration with affective collaborative robots. To know if we have succeeded we need to have metrics to measure the human-robot collaboration. Not many efforts have been done yet to come with common metrics for human-robot collaboration. The two main reasons for this are that the field is still in its infancy and that the field is very broad. Steinfeld et al. (2006) have made an effort to identify common metrics. Three different aspects of HRI are measured with their metrics: system performance, operator performance, and robot performance. In these aspects standard HCI methods are incorporated such as: effectiveness, efficiency, trust, situation awareness (both human as robot), and workload. One way to collect structured data for human-robot interaction in the field is the Robot-Assisted Search and Rescue Coding System (RASAR-CS) (Burke *et al.* 2004). In this methodology three ways of interaction are scored; human-human verbal communication, team communication, and human-robot interaction.

As shown there are metrics to measure the performance of human-robot teams, but these metrics are not tested extensively yet.

CONCLUSION

Affective collaboration is required for the next generation of robots in safety and crisis management, because the current tele-operated robots cause a cognitive workload that is very high. Better user interfaces can solve this partially, but more autonomous robots will probably help better at decreasing the cognitive workload while increasing the amount of deployed robots. To keep a high situation awareness without increasing the cognitive workload of the operator, but with enhancing the efficiency and effectiveness of rescue workers, an affective robot is necessary. If the robot is autonomous it should also take into account the affective state of the civilians in the area (injured or not) to interact with them appropriately. The identified need for affective collaborative robots in safety and crisis management is also applicable in the space and military domain. The affective collaborative robot enhances the collaboration by adapting its interaction to both the affective state of the user given the context and the social relation between robot and user. We drew knowledge from cognitive architectures, affective computing, and HRI together. With this we showed the need for affective collaborative robots and identified the core functions and requirements an affective collaborative robot should satisfy. To obtain affective robots one has to consider three core functions and the contexts of operation: sliding autonomy, affective communication, and adaptive attitude. The three core functions lead to several requirements: level of control, shared situational awareness, utterance and affect recognition and expression, ability to adapt to affective state, ability to adapt to social role, and context knowledge. Our next step is to implement the requirements and measure the impact of these requirements on the performance of a human-robot team.

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