Artificial Emotion and Social Robotics

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Abstract. Emotion is a concept increasingly used in designing autonomous robotic agents, especially for allowing the satisfaction of basic conditions crucial to the robot survival, for responding emotionally to situations experienced in the world and to humans interacting with it. But psychological evidence also suggests that emotion plays an important role in managing social interactions in groups. This document is a position paper explaining why emotion can benefit the field of distributed autonomous robotic systems. It also outlines research issues that need to be addressed to validate the usefulness of the concept of artificial emotion in social robotics.
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1 Introduction

The idea of using emotion in the design of autonomous agents is not new, and the last three years have shown a great increase in the acceptability and usability of the concept of emotion, especially in designing software agents. A small number of researchers are also using ideas related to emotion in designing robotic agents. The concept of *Artificial Emotion* is principally used in making robots respond emotionally to situations experienced in the world or to interactions with humans. One goal is to help establish the believability that the robot is actually interacting purposefully with the user and not simply executing a program. Another goal is to design computational models of emotion, derived from psychological studies or neuroscience research. How emotion can influence the learning process of an autonomous agent is also considered.

Theories in psychology indicate that emotion plays an important role in such abilities, and also point to other uses that could greatly benefit the field of distributed autonomous robotic systems. The purpose of this paper is to present new research directions involving the concept of artificial emotion in social robotics. The paper starts by reviewing research done in 'emotional' robotics, followed by summarizing indications taken from psychological studies concerning the roles of emotion. It then explains how artificial emotion can be used in social robotics, and outlines research issues that need to be addressed to validate the usefulness of the concept.

2 Emotional Robotics

The concept of emotion has just recently started to be used in mobile robotic research, mostly by emotive expression in the behavior of the robot for human-machine interactions. For instance, Velasquez's work [24] is oriented toward computational neural models of emotions necessary for satisfying basic conditions crucial to survival (e.g., escape from danger, obtain food and shelter), and integrate them in complete systems involving drives, perception, behavior and motor control. For emotions, Velásquez identified and created explicit models for six different emotion families: *Anger, Fear, Distress/Sadness, Enjoyment/Happiness, Disgust, Surprise*. The basic computational unit is made of *Releasers* which filter sensory data and identify special conditions before being sent to a neuron. Releasers can be innate (called *Natural*, creating primary emotions) or learned (from predicting the occurrence of natural releasers and used in generating secondary emotions). Each releaser has a short-term memory and can habituate to stimuli using a model of rate-sensitive habituation process. The activation of an emotional neuron, in addition to being influenced by releasers, considers temporal decay and direct influences from other neurons. Emotional learning is done using a modified Hebbian rule. In his model, mood are explained as low levels of arousal of emotion systems, and temperament are modeled through the different values of parameters (thresholds, gains and decay rate) of emotions. His work is used to control Yuppy, an emotional pet robot of the MIT AI Lab. The robot has nineteen self-interested behaviors directed in most part toward satisfying its needs and interacting with humans. It is programmed to respond emotionally to situations experienced in the world and to human interacting with it.

Another example is Kismet [1,2], designed to interact socially with human "parents". Kismet must generate meaningful interactions with the caretaker, regulating these interactions to maintain an environment suitable for the learning process, and assisting the caretaker in satisfying the robot's drive. The work focusses on the role motivations and facial expressions play in maintaining an appropriate level of stimulation during social interaction. The robot responds with expressive displays which reflects an ever-changing motivational state and which give the human cues on how to satisfy the robot's drive while neither over-whelming nor under-stimulating the robot. These emotive expressions then serve as communicative acts. The framework proposed is made of a perception system, a motivational system, an attention system, a behavior system and a motor system. An emotion subsystem is part of the motivational system. A given emotion's level of activation (ranging between [0, max] and determined by a threshold) is influenced by drives, pain and other emotions. Each drive is partitioned into three regimes (homeostatic - the operation setpoint of the drive, over-whelmed or under-whelmed) and for a given drive, each regime potentiates a different emotion and hence a different facial expression. Influences from other emotions serve to prevent conflicting emotions from becoming active at the same time, using mutually inhibitory connections. The experiments done with the Kismet robotic face involved having up to four drives (fatigue, social, security and stimulation), three consummatory behaviors (sleep, socialize and play), two visually-based percepts (face and non-face), five emotions (anger, disgust, fear, happiness and sadness) and up to ten expressive states. Fatigue and sleep create a self-regulation method used for restoring all the drives, to let the robot have some time to regulate its interaction with the external world (especially when they are inappropriate), to consolidate its learned anticipatory models and integrate them with the rest of the internal control structure. The security drive is to determine when learned anticipatory models of the effects of its actions on the world are adequate.

Emotional robotics is also concerned with learning, but only in simulation yet:

- Gadanho and Hallam [8] experimented with an emotion-based evaluation of the context to see if it can be adequately used as a reinforcement signal for policy acquisition by Q-learning. Their conclusion is that emotions do not provide a good evaluation of what is going on at any one moment, but are a sort of mixed evaluation the robot acquired from its past experiences. Emotions are more suited to modulate learning parameters and the exploration versus exploitation ratio. They also studied whether emotions can successfully fulfill the role of determining state transition in order to decide when to adapt a controller in a continuous learning experiment [9]. It resulted in drastic cuts in the number of triggerings of the learning controller while maintaining overall performance.
- Foliot and Michel [5] present an approach based on the assumption that emotion can be seen as the basis of cognition because it provides a default functional model. Their goal is to show how emotion based structures could contribute to the emergence of cognition by creating suitable learning conditions.

In regards to social robotics, the only reference found involving emotion is about an approach that uses a frustration variable to change the behavior-selection strategy, making the robots specialize in doing one of two tasks [22]. However, the approach was only validated in simulation.

3 Psychological Foundations Concerning the Roles of Emotion

Psychological research on emotion is focused primarily on three aspects: biology of emotion, emotion and interpersonal communication, and emotional development [23]. From an engineering point of view, the second aspect is more interesting. Our research suggests that emotion can serve three important roles in designing autonomous robots:

- *Emotion to Adapt to Limitations.* Emotion plays a role in determining control precedence between different behavior modes, coordinating plans and multiple goals to adapt to the contingencies of the world (under constraints of time and other limited resources), especially in imperfectly predictable environments [7,17,20]. Uncertainty prevents any complete dependence on predictive models in human planning – people typically think only a step or two ahead and they respond, moment-by-moment, to the new arrangements of the environment that their actions help to create [17]. The adaptation problems that emotion help solve are finding an equilibrium between the subject's concerns and the environment by signalling the occurrence of concern-relevant events, by recognizing the plan junctures that these events imply, and by instigating control shifts accordingly [7].
- *Emotion for Managing Social Behavior.* In relation to social behavior, Plutchik [20] interestingly points out that emotions are in direct association with the **universal problems of adaptation**, which are:
  - **Hierarchy**: dominance hierarchies are connected primarily with certain types of basic emotions, namely anger and fear. They are also connected to the personality derivatives of these emotions, which are dominance and submission.
  - **Territoriality**: the basic emotions related to territoriality are exploration and its opposite, surprise (control or dyscontrol). They are developed through exploration of the environment.
  - **Identity**: this is related to questions like who we are, what group we belong to. It is used for cooperative hunting, group defense, social signaling, social communication, built in through genetic coding mechanisms to recognize other organisms (size, shape, color, markings, sound patterns, chemical and olfactory cues). Emotions associated with identity are acceptance and rejection.
  - **Temporality**: this allows to take into consideration the limited duration of an individual's life. Distress signals for social support, nurturing responses in other members of the social group are also considered. Sadness, distress and joy contributes in solving this adaptation problem.

  These universal problems of adaptation have important implications. They provide a general way of looking at life problems, and a set of implicit dimensions that one can use to assess the environmental and/or social demands on a given species. For any group of agents, one can ask: How are problems of hierarchy, territoriality, identity and temporality expressed for that group? What kind of adaptations has the group made for dealing with each of these problems? Another implication is that they provide "another kind of rationale for the existence of certain emotions, since emotions are reflections of the adaptations that animals make to the universal problems. Since these problems are universal, the emotions that are derived from them may be thought of as universal, basic, or primary"

[20]. Plutchik's theory also suggests the possibility that emotions "are functional adaptations for establishing a kind of social equilibrium. This would imply that emotions enter into every social transaction and help to establish a balance of opposing forces. These balances are always temporary and frequently change as we move through life from one conflict to another" [20]. This is also suggested by Oatley and Johnson-Laird [17], especially in the context of creating mutual plans: "Mutual plans cannot be innately wired into the cognitive systems; they must be created in the minds of more than one individual by implicit or explicit agreement." These plans are partly under the control of both participants and partly governed by conventions of their society. One way to set up a mutual plan is to make a promise to somebody, creating an obligation and a corresponding expectation. Emotions are then used to communicate junctures in mutual plans among individuals in social groups.

- *Emotion for Interpersonal Communication.* In order for emotions to regulate behavior in social interaction, emotion also has a communicative role, as suggested in the previous paragraph. Emotion plays important functions in social signalling. Ethologists believe that emotional expression have a communicative function and act as releasers for the coordination of social behavior. There are signals that promote group cohesion, signals to communicate about external environment, and intraspecific threat signals. It is to an animal's advantage to communication its intentions, and to be sensitive to such messages from others [15]. For animals, Darwin believes that joy and anger occupy opposite ends of a single dimension of sociability, while fear would lie on a different dimension [12]. Display, the expression of emotion, has evolved as a mean of communication, generating signals to indicate how they would react to a social encounter. Emotional expression promotes individual isolation (as it may be necessary in defending something) or to promote group (as different social circumstances might require). In fact, the role of expression in emotion can be seen from three different views: the situation is evaluated by emotion that lead to an expression; expression may be a reaction to the situation that also produces the emotion; the expression may affect the emotion rather than the other way around [15]. Emotion then serves a dual purpose: it is a communication act and it is a sensed state.

The concept of emotional communication also helps explain why the great variety of human emotions depends so much upon the social context: it is because of the richness and subtlety of human social relationships [12,17]. While humans have emotions to fit virtually any kinds of social situations, animals probably only have emotions to deal with certain kinds of survival problems, and for which there are some strong adaptive pressure [12]. Complex emotion then evolved for organisms living in society and having higher cognitive ability and a flexible behavior repertoire [21]. This leads us to believe that the concept of artificial emotion is required in order to design autonomous robots showing higher level of intelligence.

4 Artificial Emotion for Social Robotics

As described in Section 2, the use of emotion for interpersonal communication is the primary focus of research involving artificial emotion. The role of emotion for adapting to limitations is partly addressed, and in spite of the psychological evidence, no research has directly addressed the use of emotions to regulate social behavior in a group of robots. The ALLIANCE architecture [18], without explicitly using the term, is the one that comes closest to the notion of artificial emotion to regulate group behavior. In a foraging task, the approach allows robots to broadcast information about their goals to affect their motivations. *Impatience* and *Acquiescence* are internal states used to coordinate the robots. By using internal states, communication and learning, ALLIANCE exploits some of the characteristics that can be associated with artificial emotion. However, we still have to make significant progress in order to design autonomous robots capable of working in real life settings (like our homes, offices, market places, etc.). Dynamic and unpredictable conditions occur constantly in everyday situations, and a robot has to deal with them with limited energy, perception, action and processing capabilities. Also, a robot operating in such conditions requires the ability to interact with different individuals (robots, humans or other types of agents). Based on Section 3, more emphasis should be put on the concept of artificial emotion in order to achieve these goals, which are related to social robotics. Here are the characteristics associated with social robotics, taken from [4], with some comments on how emotion can be associated with them:

1. *Agents are embodied.* This characteristic includes robots, humans and animals. Emotions are something that is shared (at various levels) by humans and animals, and it can be interesting to add them to robots.
2. *Agents are individuals, part of a heterogeneous group (the members are not identical and have individual features, like different sensors, different shapes and mechanics, etc.).* The number of works involving this aspect is growing [4,13,16,19]. The role of emotion in adapting to limitations of the robot (in operating and in modeling the environment) can certainly help manage the heterogeneity in a group.
3. *Agents can recognize and interact with each other and engage in social interactions as a prerequisite to developing social relationships.* "The ability to distinguish the agents with whom one is interacting from everything else in the environment is a necessary condition for intelligent interaction and group behavior" [11]. This has up to now been mostly done using IR, explicit radio communication of the positions of the robot obtained from a positioning system, and vision [3].

4. *Agents have 'histories'; they perceive and interpret the world in terms of their own experiences.* This is associated with specialization. An artificial emotion can have a level of activation affected by different factors over time, representing this way the history of past experiences.
5. *Agents can explicitly communicate with each other. Communication is grounded in imitation and interactions between agents, and meaning is transferred between two agents by sharing the same context.* Current approaches involving interaction via communication are mostly oriented toward implementing electronic media access protocol [3]. Artificial emotion can serve as a rich abstraction of the current state and goals of a robot, a kind of implicit model of its intentions. This constitutes a simple way of establishing a shared meaning and create a basis for communication, without having to transmit large amount of data.
6. *The individual agent contributes to the dynamics of the whole group (society) as well as the society contributing to the individual.* Redundancy, fault tolerance and cooperation are then important.

Also related to social robotics is the notion of cooperative robotics [3], which involves three fundamental seeds: the mechanism of cooperation, the task and system performance. Regarding the mechanism of cooperation, Cao et al. [3] indicate that the realization of cooperative behavior must rely on group architecture (homogeneity/heterogeneity, ability to recognize and model others, and communication structure), resource conflicts (to share the environment, manipulate objects and communication), how cooperative behavior is motivated and achieved, and learning. As indicated for social robotics, these issues are also considered in the role of emotions.

5 Research Issues

The arguments presented in the previous sections point toward the conclusion that the concept of artificial emotion could lead to significant contributions to the field of social robotics, much more than what has been done until now. However, no solutions are provided to clearly validate the use of such a concept in the design of autonomous robots. The following issues need to be addressed:

- What computational mechanisms are necessary for implementation of artificial emotions for social robotics? Will the approach be based on a theory of emotion, or will it be derived empirically? On what grounds can we state that the approach is actually related to the concept of artificial emotion? If we try to summarize what we found in our research, we would need the following characteristics: 1) emotions are motives – they are causes of action; 2) cognition can trigger emotions – emotions can trigger cognitive operations; 3) emotions can cause expressive actions; 4) emotions can affect purposive, goal-directed action; 5) emotions can become goals; 6) the behavior also affects emotion [15].

- How can we make robots recognize and interact with each other? This is an important problem to resolve, especially if vision is preferred over positioning systems (which require some engineering of the environment). This issue is also related to the question of how robots will communicate their emotions.
- How can we efficiently evaluate the performance of an approach based on artificial emotions? The task must be chosen so that possible comparisons with approaches not using artificial emotions can be done. It must also make the robots adapt to their limitations which can be related to their sensing and acting abilities, to their heterogeneity, to the requirement of making local decision that will affect the group (and contrarily to approach with a centralized decision mechanism), and to shared resources. For instance, the medium size RoboCup competition would make an interesting experimental setup.

6 Conclusion

Artificial emotions have up to now been mostly used for emotive expression and response in human-robot interactions. However, the concept can be used to do much more, as argued in the present paper. This paper outlines different research perspectives in social robotics that can be addressed using the concept of artificial emotions. Our goal is to encourage research in these directions in order to generate new contributions to the field of distributed autonomous robotic systems.

Fig. 1. Group of Pioneer 2 mobile robots.

For our part, based on the guidelines indicated in this paper, we are in the process of preparing experiments involving the use of artificial emotions. What we plan to do is to use our group of robots shown in Figure 1 in a foraging task. The group of robots is made of six Pioneer 2 robots, three indoor and three outdoor models. Each robot is equipped with 16 sonars, a compass, a gripper, a camera, an ethernet-modem connection and an onboard computer. Note that the gripper of the outdoor model is not able to pick up small objects directly put on the floor, and that the indoor model has more difficulty moving over small objects. The camera of one robot may also be replaced by stereo vision, to increase the heterogeneity of the group. The programming environment is Ayllu, a tool for development of behavior-based control systems for intelligent mobile robots. Foraging is an interesting task because it has been used in various group robotic research, and comparisons are then possible. Works on territoriality, dominance hierarchy and caste for group strategies [6,10] will be useful. Finding the ideal number of robots for the foraging task [6] by dynamic role selection will also be addressed. For inter-robot recognition we plan to use visual cues, generated for example using a light signaling device that has shown to be an efficient way of explicitly communicating simple information to others, and at the same time be a rich source of implicit information for recognizing and interacting with others [14]. We also plan to use a charging station as a shared resource for the group, to study how artificial emotions could help manage 'survival' of the individuals in long-lasting experiments.

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