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Research article

Intelligent emotion and behavior based on topological consciousness and adaptive resonance theory in a companion robot

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ABSTRACT

Companion or 'pet' robots can be expected to be an important part of a future in which robots contribute to our lives in many ways. An understanding of emotional interactions would be essential to such robots' behavior. To improve the cognitive and behavior systems of such robots, we propose the use of an artificial topological consciousness that uses a synthetic neurotransmitter and motivation, including a biologically inspired emotion system. A fundamental aspect of a companion robot is a cross-communication system that enables natural interactions between humans and the robot. This paper focuses on three points in the development of our proposed framework: (1) the organization of the behavior including inside-state emotion regarding the phylogenetic consciousness-based architecture; (2) a method whereby the robot can have empathy toward its human user's expressions of emotion; and (3) a method that enables the robot to select a facial expression in response to the human user, providing instant human-like 'emotion' and based on emotional intelligence (EI) that uses a biologically inspired topological online method to express, for example, encouragement or being delighted. We also demonstrate the performance of the artificial consciousness based on the complexity level and a robot's social expressions that are designed to enhance the users affinity with the robot.

Introduction

Present-day technology can improve the quality of human life by adding convenience and entertainment, saving time, making it easier to get an instant solutions for problems, and even providing therapy. The technology of computing has allowed the development of important tools, including embodied artificial machinesi.e., robots which can be designed to execute one or more tasks automatically for various purposes. Robots have become increasingly more present in humans' lives, in industry, healthcare, education, agriculture, space, and particularly in the service sector and in our homes (Halal, 2008). The greatest growth in the robotics market is currently for applications in the service sector, and the technology of information computing toward this end is rapidly improving (Lechevalier, Nishimura, & Storz, 2014; Shukla & Shukla, 2012). We are thus concentrating our research on service robotsincluding personal and social robots as such robots can make significant contributions to everyone's quality of life (Leite, Martinho, & Paiva, 2013).

Our focus is on personal robots that will need to interact with humans. The communication between humans and a personal robot will be improved if the robot can engage in emotional interactions with the humans. Because human beings comprehend each others' feelings predominantly by recognizing others' emotions expressed by their facial expressions, a personal robot should also be able to comprehend (and provide its own) facial expressions correctly. Accordingly, we have designed a robot that can recognize both its surrounding environment and human expression. We achieved this by building on the foundational research in the study of human-robot interaction (HRI).

The study of HRI is an interdisciplinary field that combines major studies of both robots and human in diverse fields such as artificial intelligence (AI), human-computer interaction (HCI), pattern recognition, control systems, electronics, mechanics, psychology, behavior expression systems, social communication, and neuroscience (Goodrich & Schultz, 2007; Murphy, Nomura, Billard, & Burke, 2010). In HRI studies, researchers usually design a robot to interact with the environment or an object, and they develop a motion strategy for a particular case (depending on the

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physical properties) without considering the motivation or stream of consciousness that characterize human behavior (Argall & Billard, 2010; Fong, Nourbakhsh, & Dautenhahn, 2003). In our research, in contrast, we have attempted to develop a method with which a robot can recognize the facial expressions of humans and also demonstrate its own emotional expressions, depending on its 'motivation' based on a 'consciousness' system.

Regarding the concept of emotional intelligence (EI), our proposed robot is also designed to consider the social etiquette that humans use for emotional expressions. To illustrate, if you are happy while your friends around you are feeling sad, when you recognize your friends' sadness you might deliberately express an emotion other happiness because relationship conflict might develop if you express an emotion opposite that of your friends'. You might show neutrality or pretend to be sad in order to share your friends' feeling and express sympathy in order to maintain the relationship. In effect, you alter your facial expression and demeanor to maintain social relationships. A robot should thus have similar 'empathy' and 'sympathy' (as illustrated in Fig. 1), and this topic is the primary focus of this paper.

Human-robot interactions are complicated communication, and HRI consolidates various interdisciplinary fields including robotics, HCI, AI, social science, and cognitive psychology. We therefore designed the proposed system with a multi-agent system (MAS) comprised of multiple interacting intelligent agents to process the various tasks and different functions. The MAS also plays the primary role in social robots because a MAS includes individual autonomous agents that can observe environmental states, the learning state, or the action state related to cognitive processes, and a MAS can also include sub-states depending on the complexity of the system (Byrski, Dreżewski, Siwik, & Kisiel-Dorohinicki, 2015; Panait & Luke, 2005).

We also utilize aspects of a MAS, i.e., the perception state, consciousness state, action state, and expression state, which we describe in the next section. In this paper, we describe and launch our system of conscious behavior decision as an agent. using the biologically inspired topological adaptive resonance theory (TopoART). The TopoART is used for fast online learning, and it is robust and stable for dealing with 'noisy' data. The TopoART improves the ART by using topology learning with the addition of sub-networks at different levels of detail (Tscherepanow, 2011), and thus the TopoART is more suitable for real-world information. The machine learning of biologically inspired networks also includes learning methods such as the Self-Organizing Map (SOM) (Kohonen, 1982) and Perceptron (Rosenblatt, 1958). However, the SOM and Perceptron methods are quite wide of the real-world information because they are sensitive to noisy information and are not a form of online learning.

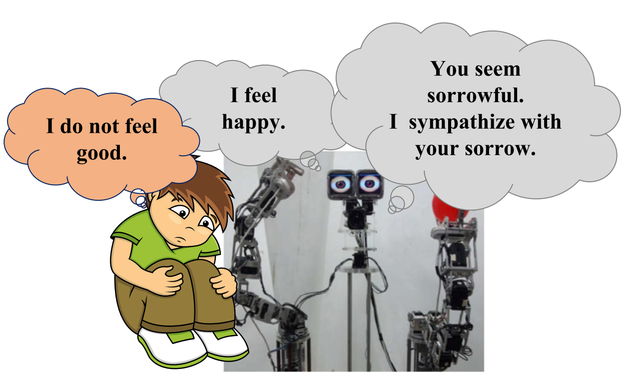

Fig. 1. The proposed concept of a 'companion robot' based on social-emotional intelligence.

Since humans are social animals that generally cooperate with each other in order to survivd, a personal-use, companion or 'pet' robot should have the skill to perceive the social signals of emotion expressed by humans and by itself. This is regarded as EI skills or social intelligence (SI) (Goleman, 2001; Salovey & Mayer, 1990). We highlight EI and SI in a robot by implementing and demonstrating the new reorganized EI state within this research framework. The goal is to create a robot that can be a socially autonomous agent as an intelligent companion for a human.

As a first signal system of social interaction, human emotions are expressed by universally recognized facial expressions, body language and mannerisms (Ekman, Freisen, & Ancoli, 1980). A pet robot should thus represent its 'feelings' on its face, because that is the primary way that humans communicate feelings. Facial expression is a fundamental manifestation of human emotion that is driven and conditionally followed by a neurological mechanism and by moving muscles beneath the skin in accord with the formation of a cortical route in the brain (Rinn, 1984).

Many studies on facial expression recognition (FER) have attempted to classify emotion. These studies used a recognition algorithm together with some machine learning algorithms. Support vector machines (SVMs) are a popular way of analyzing data and recognizing patterns for classification (Cortes & Vapnik, 1995). Other methods include hidden Markov models (HMMs) (Rabiner, 1989) and a principal component analysis (Abdi & Williams, 2010; Lin, 2006). To implement an FER system, a facial feature extraction method must first be applied, and several facial feature extraction models have been proposed including the active shape model (ASM) (Cootes, Taylor, Cooper, & Graham, 1995), the active appearance model (AAM) (Cootes, Edwards, & Taylor, 2001), and the constrained local model (CLM) (Cristinacce & Cootes, 2006).

These facial feature extraction models have also been used in medical research to better classify and fit the element region of X-ray images autonomously. One application of the research on ASM, AAM and CLM is presented by Van Ginneken, Frangi, Staal, Romeny, and Viergever (2002), who developed an ASM with optimal features for medical image segmentation. These methods are currently being considered for building companion robots.

Traditionally, robots have acted by following a human instruction to achieve the human's aim, based on the physical properties of the robot in question and on mathematical models for solving the problem at hand. With those robots, cognitive aspects such as consciousness were not considered, and the robots did not behave in a natural behavior-based manner. Robots could not interact consciously with humans because the cognitive processes of humans and the simple programming of a robot are different. McCarthy therefore proposed the need for human-interacting robots that would someday have functions that correspond to instincts (which in humans is a consciousness process), emotions, cravings, philosophy and introspective knowledge that the artificial agent can perform its behavior in the common creature nature (McCarthy, 1995).

For this reason, it is crucial that a pet robots behavior embodies a consciousness that is a medium agent of two termini: a logic system without behavior, and behavior without representation. This aspect was described by Thao et al.. A lower-order animal such as an insect can engage in simple actions, and higher-order animals that have more complex brains can engage in actions that are much more complex, and highest-order animals can experience emotions. Such emotions may contribute to the animal's survival. For example, when we humans encounter a dangerous situation, we feel the emotion of fear that works to remind us of situations we should avoid.

We have been attempting to create a personal robot that can perform and engage in human interactions supported by 'motiva-