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Emotionally expressive dynamic physical behaviors in robots

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ABSTRACT

For social robots to respond to humans in an appropriate manner, they need to use apt affect displays, revealing underlying emotional intelligence. We present an artificial emotional intelligence system for robots, with both a generative and a perceptual aspect. On the generative side, we explore the expressive capabilities of an abstract, faceless, creature-like robot, with very few degrees of freedom, lacking both facial expressions and the complex humanoid design found often in emotionally expressive robots. We validate our system in a series of experiments: in one study, we find an advantage in classification for animated vs static affect expressions and advantages in valence and arousal estimation and personal preference ratings for both animated vs static and physical vs on-screen expressions. In a second experiment, we show that our parametrically generated expression variables correlate with the intended user affect perception. Combining the generative system with a perceptual component of natural language sentiment analysis, we show in a third experiment that our automatically generated affect responses cause participants to show signs of increased engagement and enjoyment compared with arbitrarily chosen comparable motion parameters.

1. Introduction

The ability to express emotion through nonverbal means can be an effective tool for computational and mechanical systems which interact with people. Coulson's component process view of emotions is defined as the "affective significance of a series of evaluations" (Cañamero and Aylett, 2008). This relationship between cognition and evaluation often results in some physical behavior such as a smile or scream. These physical behaviors are usually an unconscious reaction and can be considered representations of one's internal states.

There is a large body of evidence which supports facial expressions and prosodic cues as being indicative of a person's internal emotional state (Ekman, 1993; Fridlund et al., 1987; Schuller et al., 2006, 2011). However, the question of whether pose and body movements are reflections of internal emotional states has been subject to debate for many years. Some studies suggest emotional body language and physical expression are used primarily for social and communicative purposes rather than an unconscious expression of internal emotion (Fridlund, 1991; Kraut and Johnston, 1979). Though in more recent years evidence has been mounting which suggests the opposite is true. There is indeed a direct relationship between external physical behavior and emotional states (Inderbitzin et al., 2011; Walbott, 1998). In fact, Aviezer et al. (2012) declare that body language instead of facial expression better broadcasts what a person is experiencing especially in circumstances of extreme positively or negatively valenced emotions.

Other research also demonstrates that gesture is useful for conveying information other than affect and is a component of the speech planning process (Alibali et al., 2000; Kita et al., 2007). In essence, gesture aids speech generation beyond lexical retrieval by helping speakers to organize and conceptualize spatial information. Movement is also important for interactive scenarios. The timing of visual cues including movement illustrators and gaze plays an important role in the collaborative process of conversation (Bavelas et al., 2002; Bavelas and Chovil, 2006). In fact, Bavelas and Chovil (2000) describe an integrated model of communication which unifies the visible and audible components of face-to-face dialogue.

Though the debate concerning the true function of body pose and body movements remains, and it appears the use of gesture has many functions, it is largely accepted that, at some level, people are able to associate postures and movements with particular emotions (de Gelder, 2006; Nele Dael and Scherer, 2012; Coulson, 2004; Krauss et al., 1991; Kipp and Martin, 2009). There is even evidence of the brain processing emotional body language unconsciously and without reliance on the primary visual cortex (de Gelder and Hadjikhani, 2006). The human ability to recognize emotion through body language is an important trait and quite relevant to the field of affective computing. Additionally, the capacity for processing emotion through

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a non-conscious "affective channel" is an important attribute which strengthens the argument for emotionally expressive machines (Picard, 1995). This enables communication without increased cognitive function from the user. This is especially important in machine–human social interactions in which the machine should support the natural tendencies of human communication.

In this paper, we further explore the use of body language and physical motion of a robot as a means for expressing emotion. Expressive movements should not merely be considered a sequence of varied positions, but rather an additional form of communication and a behavior which can carry influence in a socially interactive environment (Frijda, 1987). Physical behaviors have components which are both representative and interactive, often modifying the relationship and emotions among multiple actors.

Robots that demonstrate a sensitivity to people's emotional states by responding with such expressive movements and behaviors enable more natural, engaging, and comfortable human–robotic interactions (Kozima and Yano, 2001; Breazeal and Aryananda, 2002; Castellano et al., 2010). An emotionally responsive and expressive robot can be incredibly effective in social situations such as in learning and teaching environments (Scheutz et al., 2006) by communicating pieces of information including levels of compassion, awareness, accuracy, and competency all through a non-conscious affective channel. For these reasons designing and developing emotionally expressive and perceptive robots has been a focus of many researchers in the field as described in Section 2.

We contribute to this research by examining a robot's ability to (1) express emotion using non-facial physical behaviors and (2) autonomously generate affective behaviors. We investigate several questions. What aspects of human physical emotional expression can be translated to robotics? Can limitations such as range of motion, the number of degrees of freedom (DoFs), velocity restrictions, and non-humanoid design be surmounted so that a robot can still be naturally and intuitively communicative through physical expression? Can emotionally perceptive robots offer increased levels of engagement in human robotic interactions by responding with expressive movements?

We address these questions by first reviewing a number of strategies and efforts to communicate emotion through a nonverbal channel in animation and robotics. Next, we introduce our robot, *Shimi*, and describe our own efforts for enabling Shimi to convey affective behavior through physical gestures and evaluate our efforts with a user study. We then describe a set of variables we believe to be essential to creating emotionally expressive motion and behavior. Using these variables, we introduce a novel computational architecture for algorithmically generating affective physical behaviors in Shimi which we evaluate with additional user studies. Finally, we evaluate the entire system with a final user study based on a human–robotic interaction involving communication.

2. Emotionally expressive systems

2.1. Utility of affective computing

Some debate in the HCI community exists regarding whether machines should attempt to detect and display emotion. Emotional displays can allow observers to interpret a person's beliefs and intentions. However, Muller (2004) argues that there is currently no method for discriminating between parts and wholes. For example, a computer user might demonstrate frustration for any number of reasons such as a faulty mouse or a non-user friendly software interface. An emotionally intelligent machine would detect the frustration, interpret it as resulting from the whole experience, and modify its own behavior accordingly. Should the machine modify its behavior without fully understanding the source of the frustration? Muller postulates that doing so might not be the optimal solution and ultimately could lead to even more distraction and frustration for the user.

Though differentiating between the possible sources and causes of emotions may be difficult, the amount of useful information within the emotional signal is so significant that the common view is that the benefits of emotional intelligence outweigh any potential mishaps. This is especially true in the context of sociable robots in which the machine is a partner and not merely a tool. In social settings, emotions can be used as a means of influence to elicit responses from other contributors and improve group efficiency by minimizing social conflicts (Frank, 1988; Campos et al., 2003; Frijda, 1987; Simon, 1967). Leveraging these benefits requires functionalities for both emotion detection and synthesis and evaluation is based on whether such emotional intelligence benefits an agent's reasoning process, improves performance, and creates human–computer interactions that are effective, productive, and enjoyable.

2.2. Virtual agents

The idea of turning nonliving objects into expressive beings with an abundance of personality has been a hallmark of computer animation for decades. Lasseter (1987) describes the use of pose, motion, and acceleration in animating the iconic Pixar lamp, *Luxo Jr*. Some of the most important techniques Lasseter presents are "staging" and "exaggeration" which together represent the artistry of presenting an idea so that it is unmistakably clear by developing its essence to extreme proportions. "If a character is sad, make him sadder; if he is bright, make him shine; worried, make him fret; wild, make him frantic."

Studies have shown that these ideas are appropriate for robots as well. Gielniak and Thomaz (2012) demonstrate that it is not human-like motions, but rather the exaggerated cartoon-like motions of a robot which are most effective for yielding the benefits of increased partner engagement and entertainment value. The interactive graphics-based agent, *Rea*, is a virtual real-estate agent who uses gestures, gaze, and facial expressions as an additional communicative and expressive layer to accompany her speech (Cassell et al., 2000). Nayak and Turk (2005) describe how emotional expression in virtual agents is achieved through a combination of facial expressions and body language including torso, shoulder, head, and leg movements.

2.3. Robots

Emotionally expressive animations have demonstrated effectiveness by making the agents more relatable and lifelike. This encourages the viewer to empathize with and respond to the virtual agent as if it were human. Using animation techniques is useful in robotics and often animating virtual agents is a first step to robotic motion generation (Salem et al., 2010). Applying the methods of animation to robotics is a challenging task because there is often less mobility, fewer degrees-of-freedom, and slower movement. However, the proximity and presence of a physical robot can have many benefits. In this section, we describe related work in robotic communication through gaze, gesture, and proxemics.

2.3.1. Gaze and facial expression

Gaze and facial expression play an important role in the communicative and interaction abilities of social robotics. Even simple glances and postural shifts can encourage the flow of dialogue (Sidner et al., 2004; Cassell et al., 2001). It has also been shown that people accept robots as proactive communicative agents and respond to a robot's gaze and nods in the same manner as they respond to other humans (Muhl and Nagai, 2007; Sidner et al., 2006). The role of gaze and facial