Consensus-based Emotional Interaction Model for Emotion Regulation through Human-Robot Interaction

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***Abstract*—This position paper presents a human robot interaction framework for emotional regulation through social interaction with a robotic agent using a consensus-based algorithm and a multi-agent control approach. This model-based framework provides a parameterized and dynamic approach for emotional interaction with a robotic agent, and can be applied to social robotic-based therapies and virtual agent-based social/emotional interactive studies.**

Keywords-social robotics; emotional interaction; consensus model; multi-agent based social interaction

I. Introduction

Human-robot interaction has been a fast growing field of research, having its application domains on social interaction, assistive robotics, behavioral therapy, and educational robotics [1-3]. Study on regulating and expressing emotions through physical or animation-based facial expressions through robotic platforms has been conducted with many systems [4,5].

What needs to be researched further, given that there are sufficient work on artificial representation of emotions through robotic agents, is that an efficient framework for modeling and guiding the emotional interaction between human and robots. For the interaction with robots to have some implications on the daily lives of humans, the robot should be equipped with its own control mechanism for regulating its emotional status for the purpose of causing positive changes on the emotional status of humans. For this purpose, we take the approach of agent-based emotional interaction using a consensus-based approach [6].

II. Robot-based Social and Emotional Interaction

A. Related Work

Robotic emotions, which enables a robotic entity to function as a social agent, has made consistent progress over the past decades. Breazeal's artificial facial expression framework [8] has inspired many research projects in social robotics [9,10], and Scassellati's approach [11] based on the Theory of Mind has enabled diverse multi-disciplinary approaches in terms of human robot interaction. Study on the effects of robotic facial expression in terms of interactive learning scenarios [12] and turn-taking based methodology in terms of human-robot interaction [13,14] were among many exemplary research in social robotics.

B. Consensus-based Emotoinal Interaction Model

While previous studies focused more on expressing artificial emotions through robotic systems, estimating emotional responses of humans, or assessing engagement in task-based settings, realistic model for emotional interaction has not shown much progress. This research proposes to provide a novel theoretical framework for emotional interaction by incorporating consensus theory on emotional engagements. Our model includes three emotional agents: human emotion, robotic emotion, and a target emotional goal for emotional regulation and therapy.

Our emotional domain is based on the 2- dimensional (2D) mapping of emotions with arousal (A) and valence (V) based on Russell's circumplex model [7]. In this 2D plot (Fig.1), we can then represent a person's emotional status as x_H and a robotic agent's emotional status as x_R. By adding an emotional

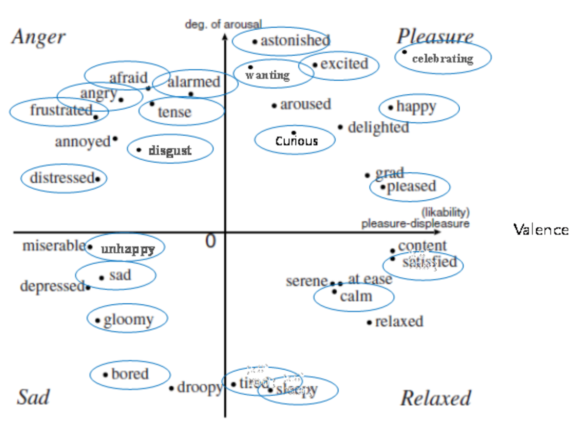

Figure 1. The emotional mapping of our agent (robotic) system based on Russell's circumplex model [7].

Research partially supported by the National Institutes of Health (NIH)

regulation goal of x_G, we can then form a consensus equation as in (1): ($B()$: *character bias function*, a_R : $approach\ rate$)

$$\dot{x_R} = B(a_R \sum_j (x_j - x_R)) \tag{1}$$

The consensus approach guarantees the convergence of multi-agents. Although the human node x_H is not controllable, all the nodes exists in a bounded domain (bounded input, bounded output) and thus provides connected stability for emotional interaction and regulation.

III. Emotional Interactin Model for Socially Assistive Robotics

In applying the consensus algorithm, we design extra mechanisms for emotional interaction: rapport and character. Since the human agent is not controllable directly, the robot dynamically allocates the goal node to initially approach the human's emotion to form a rapport with the user and then gradually moves the goal emotion to the target emotion for emotional regulation. Thus the consensus algorithm can gradually lead the human's emotion to the desired emotional state with the interactions with the robotic agent and the moving goal emotion.

The second mechanism of character is represented by $B()$, which is a $character\ bias\ function$, and a_R, which is an $approach\ rate$. One simple model can be a linear speed model in which the speed of emotional change on the 2D emotional plan is linear to the output of control algorithm (1). Another example can be a spring-damper model which takes into account of the directional input of emotional change (spring term) and the resistance of abrupt emotional change (damping term) based on the emotional characteristic of the agent.

To show the feasibility of this methodology, this work employed robotic characters designed in [15] and created a graphical user interface (GUI) based emotional game (as shown in Fig. 2) in which the robotic agent and human expresses emotions in a turn-taking fashion.

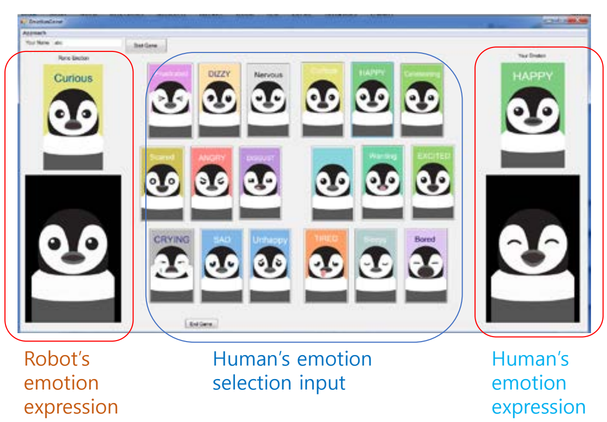

Figure 2. GUI-based emotional interaction game with character-based agents.

The emotional interaction protocol then becomes:

1) *Robot expresses its initial emotion (animation in left)*
2) *Human clicks on the emotional state that are closest*
3) *Emotoinal expression of the human user is expressed in the right*
4) *Robot agent allocates the target goal location and the temporary goal (e.g. target="happy" and temp.goal="sad")*
5) *Robot calculates the consensus algorithm*
6) *Robot projects its emotion considering the characteristic constraints*
7) *Robot shows its new emotional expression.*

IV. Results

Fig. 3 shows one case interaction between the robot and a human user, with the robot calculating its consensus equations based on the linear model for its emotional changes. This model temporarily follows too closely to the human user's emotion (thus showing just "mimicking" of human emotion), but then gradually lead toward positive emotional states.

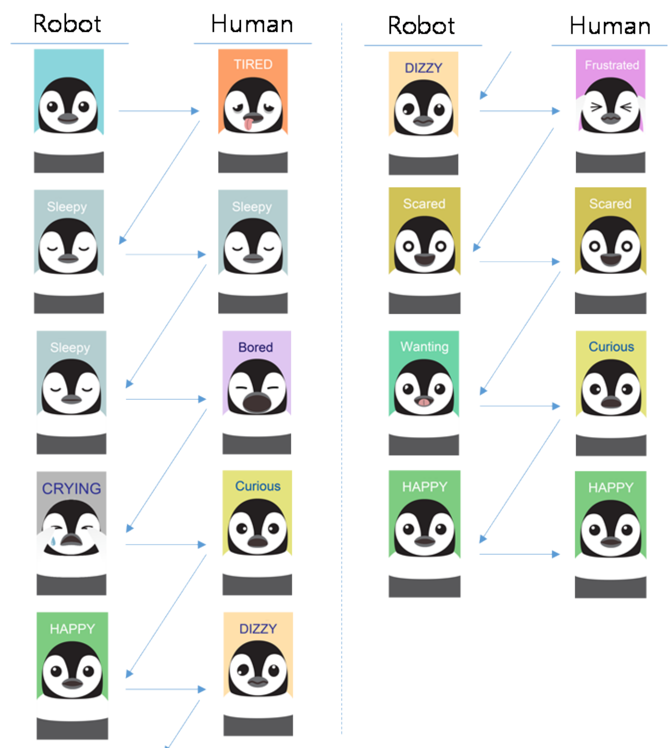

Figure 3. Emotion game example with the robot's emotional change model being linear.

Fig. 4 (on next page) shows another case with the robot utilizing the spring-damper model for its characteristic model. The flow of the emotional change can be seen as more "smooth" than the linear model, but sometimes a bit "slow" or "indifferent" to user's emotional change. Based on these two comparative scenarios, we can see that this framework is feasible of modeling different emotional characters as well as interacting with human user while emotionally guiding (regulating) for therapeutic or social purposes.

V. Discussion

This work presents a new framework for emotional human-robot interaction with multi-agent based consensus approach. To further advance the model, the author plans to apply reinforcement learning so the robotic agent can learn to "better" interact with human emotion by learning different policies (emotional interaction tactics) as well as applying prior understanding of psychology into artificial agents.

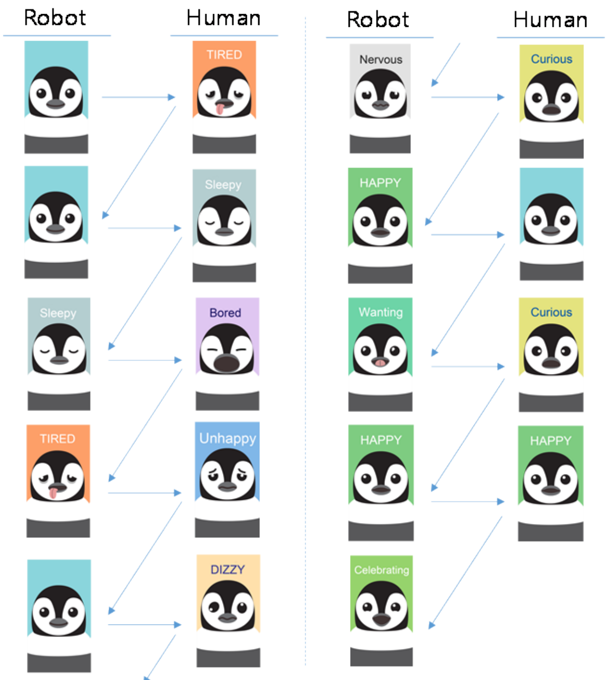

Figure 4. Emotion game example with the robot's emotional change model including the damping component.

Acknowledgment *(Heading 5)*

This research is partially supported by the National Institutes of Health (NIH) under grant # 5 R01 HD082914-04 through the National Robotics Initiative. The author would also like to appreciate Hyung Jung Kim and Rachael Bevill for their support with the animation characters and Dr. Myounghoon Jeon for his consultation on the circumplex model.

References

[1] A. Tapus, M.J. Matarić, and B. Scasselati, "Socially assistive robotics [grand challenges of robotics]," *Robotics & Automation Magazine*, IEEE, vol. 14(1), 2007, pp. 35-42.

[2] B. Robins, D. Kerstin, R. T. Boekhorst, and A. Billard, "Robotic assistants in therapy and education of children with autism: can a small humanoid robot help encourage social interaction skills?," *Universal Access in the Information Society*, vol. 4, no. 2, 2005, pp. 105-120.

[3] D. Feil-Seifer, S. Kristine, and M. J. Matarić. "Benchmarks for evaluating socially assistive robotics," *Interaction Studies*, vol. 8, no. 3, 2007, pp. 423-439.

[4] C. Breazeal, "Emotion and sociable humanoid robots." *International Journal of Human-Computer Studies*, vol. 59, no. 1, 2003, pp.119-155.

[5] H.R. Kim, K.W. Lee, and D.S. Kwon, "August. Emotional interaction model for a service robot," In *IEEE International Workshop on Robot and Human Interactive Communication (ROMAN), 2005,* pp. 672-678.

[6] R. Olfati-Saber, A. Fax, and R.M. Murray, "Consensus and cooperation in networked multi-agent systems," *Proceedings of the IEEE*, vol. 95, no. 1, 2007, pp. 215-233.

[7] J. Posner, J.A. Russell, and B.S. Peterson, "The circumplex model of affect: An integrative approach to affective neuroscience, cognitive development, and psychopathology," *Development and psychopathology*, vol. 17, no. 3, 2005, pp.715-734.

[8] C. Breazeal, "Toward sociable robots." *Robotics and autonomous systems*, vol. 42, no. 3, 2003, pp. 167-175.

[9] D. Feil-Seifer and M. J. Matarić. "Defining socially assistive robotics." In the 9th International Conference on Rehabilitation Robotics (ICORR 2005), 2005, pp. 465-468.

[10] T. Fong, I. Nourbakhsh, and K. Dautenhahn, "A survey of socially interactive robots." *Robotics and autonomous systems*, vol. 42, no. 3, 2003, pp. 143-166.

[11] B. Scassellati, "Theory of mind for a humanoid robot." *Autonomous Robots*, vol. 12, no. 1, 2002, pp. 13-24.

[12] A. L. Pais, B. D. Argall, and A. G. Billard. "Assessing interaction dynamics in the context of robot programming by demonstration." *International Journal of Social Robotics*, vol. 5, no. 4, 2013, pp. 477-490.

[13] A. L. Thomaz and C. Chao, "Turn-taking based on information flow for fluent human-robot interaction." *AI Magazine*, vol. 32, no. 4, 2011, pp. 53-63.

[14] H. W. Park and A. Howard, "Providing tablets as collaborative-task workspace for human-robot interaction," *Proceedings of the 8th ACM/IEEE international conference on Human-robot interaction*, 2013, pp. 207-208.

[15] R. Bevill, C.H. Park, H.J. Kim, J.W. Lee, A. Rennie, M. Jeon, and A. M. Howard. "Interactive robotic framework for multi-sensory therapy for children with autism spectrum disorder." In 2016 11th ACM/IEEE International Conference on Human-Robot Interaction (HRI), 2016, pp. 421-422.