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Probability of Love between Robots and Humans

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Abstract— **In order to develop a close relationship between humans and robots, we proposed a multi-modal sentimental model which considers both long and short term affective parameters of interaction. Our model is inspired from scientific studies of love in humans and aims to generate a bi-directional love between humans and robots. We refer to this sentimental connection as ˵Lovotics˝ . We have formulated probabilistic mathematical models for identified factors of love, and aim to provide a clear, distinct and discrete interpretation of the intimacy between humans and robots. Such mathematical models are assembled by a Bayesian Network depicting the relationship between intimacy and the causal factors for love. Furthermore, a novel affective state transition system is proposed which takes into account not only the current state caused by interactions, but also the effects of the previous states and internal factors of the robot. Hence, the robot is capable of acting consistently and naturally. The behavior of the robot is controlled by the above two modules via an Artificial Neural Network to develop a realistic affective communication between a human and a robot.**

I. INTRODUCTION

Several robotics researchers investigate methods to bring robots into every day life by reducing the gap between humans and robots in various aspects. Some of them focused mainly on the appearance to make the robot more lifelike [1], [2]. Some of them made an effort in expressing emotions in a more human way such as gestures and facial expressions [3], [4]. In addition, there are researches on social robots which target interactions between robots and their surrounding social environments [5], [6]. Moreover, Affective Computing researchers try to develop systems which can recognize, interpret and process human emotions [7], [8]. Ethical issues are also brought out and being formulated with the improvement of robotics technology [9], [10]. However, much more attempt is required in order to make robots which are similar to human both psychologically and physically. More focus should be on investigating the human system and apply the theories to the robot in order to give it human-like behaviors.

In human beings, emotions are not computed by a centralized neural system and operate at many time scales and at many behavioral levels [11]. Human Love and social bonding employ a push-pull mechanism that activates reward and motivation pathways [12]. This mechanism overcomes social distance by deactivating networks used for critical social assessment and negative emotions, while it bonds individuals through the involvement of the reward circuitry, explaining the power of love to motivate and exhilarate [13]. Human empathy probably reflects admixtures of more primitive affective resonance or contagion mechanisms, melded with developmentally later-arriving emotion identification, and theory of mind/perspective taking [14].

Inspiring from human affection functionality, we propose a multi-modal system which considers both short and long term effective parameters of affection. The aim of this system is to pave the way to create personal relationships between humans and robots in the form of ˵Lovotics˝ to exhibit love between human and robotics.

The main novelties of this paper are:

- A system for bi-directional sentimental affection between robots and humans is proposed.
- Probabilistic effects of 13 parameters on improving love between a robot and a human is described to develop a Bayesian network for calculating the long-term love state.
- An Affective State Transition system is proposed which could be employed to manage alteration of the short-term affective properties of the robot.
- Behavioral module of the robot is proposed to combine both effects of short and long term sentimental modules via an Artificial Neural Network.

The overall system structure is presented in Chapter II. Love State Assembly and Affective State Transition modules are described in Chapters III and IV respectively. Robot's behaviors are briefly illustrated in Chapter V. Chapter VI presents implementation of the proposed model and finally this work is concluded in Chapter VII.

II. SYSTEM DESCRIPTION

Audio and touch are channels of interaction between Lovotics and humans as illustrated in Figure 1. A wealth of information about a person's emotions and state of mind can be drawn from an audio input. By identifying the effects of emotion on speech and choosing an appropriate representation, the generation of affect is possible and can become computational. Tempo, pitch, number of harmonics, envelope, and

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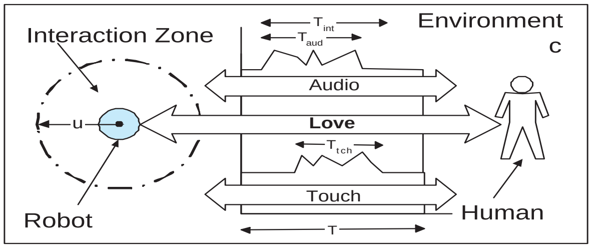

Fig. 1. Schematic of the Love Assembly State module

amplitude are the main parameters that characterize emotional cues within a voice [15], [16]. Lovotics employs a paralanguage analysis to get information from the environment and generates audio responses accordingly.
Furthermore, interpersonal tactile stimulation provides an effective means of influencing people's social behaviors and emotions such as modulating their tendency to comply with requests, in affecting people's attitudes toward specific services, in creating bonds between couples or groups, and in strengthening romantic relationships [17]. Hence, we chose touch as another interactive channel for Lovotics.

III. LOVE STATE ASSEMBLY

We employed love assembly module to calculate probabilistic parameters of love between a human and a robot.

A. Definitions and notations

Following definitions are used for the Love State Assembly module:

- Interactive zone of a robot is defined as an area in which a robot interacts with a human. It can be defined according to the physical properties of a robot e.g. size,
- Interaction happens when human locates inside interactive zone of a robot,
- Audio parameters include Number of Harmonics, Amplitude, Pitch, Tempo and Envelope.

Also following notations are used:

- u is the interactive radius of the robot according to the interactive zone,
- c is the area of the environment,
- Ara_{rbt} is the area of the robot's surface,
- Ara_{tch} is the area of the robot's surface which is touched by the human,
- T is the time of considering the system for computation in the Love State Assembly module,
- T_{int} is the total time that robot and human are interacting either through audio or touch chancels,
- T_{aud} is the total time of human-robot interaction via audio channel,
- T_{tch} is the total time of human-robot interaction via touch channel,
- T_{asy} is the total time that asynchronous similarity is visible in the human and robot audio parameters.

B. Love Probabilities

Through many years of investigating human love, researchers have discovered several factors resulting in human love. Among them, factors such as propinquity, proximity, repeated exposure, similarity, desirability, attachment, reciprocal liking, satisfaction, privacy, chronemics, attraction, form and mirroring have been noted as some of the main reasons for love [18-26]. These effective factors could be taken into account in the robot to develop a systematic method for appraising level of love between a robot and a human. We have formulated probabilistic mathematical models for these 13 identified factors of love to provide an interpretation of the intimacy between humans and robots. Such mathematical models can be presented by a Bayesian Network depicting the relationship between love and its causal factors.

1) Proximity: Physical distance between humans plays an important role in their feelings for each other [18], [19]. We mapped the effects of physical distance over into audio, with the aim of using audio proximity to emulate the effects of physical distance. A human is within the proximity of the robot when the location of the human is inside the interactive zone of the robot. Hence the probability of proximity is chance of human to be located inside the interactive zone of the robot.

$$P(Prox) = \frac{\pi u^2}{C} \tag{1}$$

where u is the radius of interactive zone.

2) Propinquity: Propinquity represents the familiarity in terms of spending time with each other [20]. The robot and human spend time together if their distance is within the interactive zone and having interactions.

$$P(Prop) = \frac{T_{int}}{T} \tag{2}$$

3) Repeated Exposure: Repeated exposure to a particular individual can increase the familiarity and hence the feeling of liking for that individual [18]. A human and a robot have exposure when human moves from outside of the interactive zone of the robot to inside.

$$P(Expo) = P(Prox)(1 - P(Prox)) = \frac{\pi u^2}{C}(1 - \frac{\pi u^2}{C}) \tag{3}$$

4) Similarity: The degree of similarity between two people is directly related to the feeling of love [18], [20]. Similarity between a robot and a human can be calculated via comparing their audio parameters.

$$P(Siml) = 1 - \frac{|Audio_{Robot} - Audio_{Human}|}{Audio_{Range}} \tag{4}$$

Equation 4 finds the difference between human audio parameters ($Audio_{Human}$) and robot audio parameters

($Audio_{Robot}$) and calculates the probability of similarity within the audio range ($Audio_{Range}$).

5) Desirability : The desirable characteristics of the other can automatically release a strong attraction which can lead to the cases of love at first sight [18], [20]. In order to find the desirability of a person for the robot, audio input from the human can be compared to predefined desired audio parameters of the robot.

$$P(Desr) = 1 - \frac{|Audio_{Human} - Audio_{Desire}|}{Audio_{Range}} \tag{5}$$

By comparing the actual ($Audio_{Human}$) and desired ($Audio_{Desire}$) audio parameters of the human within the audio range probability of desirability could be calculated according to equation 5.

6) Attachment: Attachment represents the important emotional bonding between humans [21], [18], [22]. A human and robot are defined attached when the human stays within interactive zone of the robot for long time and human touches the robot. Hence, the overall probability of attachment depends on both interaction (int_{Aud}) and touch (int_{Tch}).

$$\begin{aligned} P(Atch) &= P(int_{tch} \cap int_{aud}) = P(int_{tch})P(int_{tch}|int_{Aud}) \\ &= \frac{T_{tch}}{T}\frac{T_{int}}{T} \end{aligned} \tag{6}$$

In the same manner, other probabilities can be calculated accordingly.

7) Reciprocal liking: Being liked by an other will increase the positive feelings to that other which will influence the feeling of love [18], [20]. Since it is not possible for the robot to directly understand the love feeling of the human, the probability of reciprocal liking can be estimated indirectly via observing human behaviors. We assume that human would touch the robot more if he/she likes the robot.

$$P(Recp) = \frac{T_{tch}}{T}\frac{Ara_{tch}}{Ara_{rbt}} \tag{7}$$

8) Satisfaction: Filling the needs of the other will increase the satisfaction of him/her and hence lead to a positive feeling of love [18], [20]. The robot needs to be close to the human being and to be touched by the human, so effective parameters of proximity, repeated exposure and touch could effect the satisfaction of the robot.

$$\begin{aligned} P(Stfc) &= \frac{\pi u^2}{C}\frac{\pi u^2}{C}(1 - \frac{\pi u^2}{C})\frac{T_{tch}}{T}\frac{Ara_{tch}}{Ara_{rbt}} \\ &= \frac{\pi^2 u^4}{C^2}\frac{T_{tch}}{T}\frac{Ara_{tch}}{Ara_{rbt}}(1 - \frac{\pi u^2}{C}) \end{aligned} \tag{8}$$

9) Privacy: Spending time together and have a close interaction with each other can also improve the love feelings [18]. The robot and human have private time together if their distance is within the interactive zone and having interactions.

$$P(Prvc) = \frac{\pi u^2}{C}\frac{T_{int}}{T} \tag{9}$$

10) Chronemics: Chronemics is the study of the use of time in nonverbal communication [23], [24], [25]. It can be modeled as a function of asynchronous similarity time, touch interaction time and audio interaction time.

$$P(Chrn) = \frac{T_{asy}}{T}\frac{t_{tch}}{T}\frac{T_{aud}}{T} \tag{10}$$

11) Attraction: Interpersonal attraction acts like a force drawing people together and influence the feeling of love [18]. Attraction between a human and a robot can be modeled as a function of time, force and area of touch:

$$P(Atrc) = \frac{t_{tch}}{T}\frac{f}{F}\frac{Ara_{tch}}{Ara_{rbt}} \tag{11}$$

12) Form: The form of interaction is also important in formulating love states [25]. Force and area of touch generate the form of interaction between the human and the robot.

$$P(Form) = \frac{f}{F}\frac{Ara_{tch}}{Ara_{rbt}} \tag{12}$$

13) Mirroring: Mirroring refers to matching the audio parameters of our robot with that of the person. It has been shown that higher degree of synchronization between interactants are reflective of higher levels of interest between them [26]. Asynchronous audio variables of the robot and human could be compared to find similar properties in different time.

$$P(Mirr) = \frac{T_{asy}}{T} \tag{13}$$

C. Love State Assembly via a Bayesian Network

According to the presented probabilistic nature of above 13 parameters, a Bayesian Network can be employed to link audio, touch and location to these effective parameters in order to estimate the long-term probability of love. Proposed Bayesian Network is presented in Figure 2. This Bayesian network analyzes various causal parameters of love between the robot and the human that can be categorized in three groups:

- Human and robot distance and their interaction,
- Synchronous and asynchronous audio parameters of the human and the robot,
- Duration, force and area of the touch.

Above variables can be correlated with their conditional independencies via a directed acyclic graph to generate a probabilistic model that consists of location, audio and touch variables as system inputs, 13 causes of love as intermediate events and overall love probability as the outcome of the Bayesian Network.

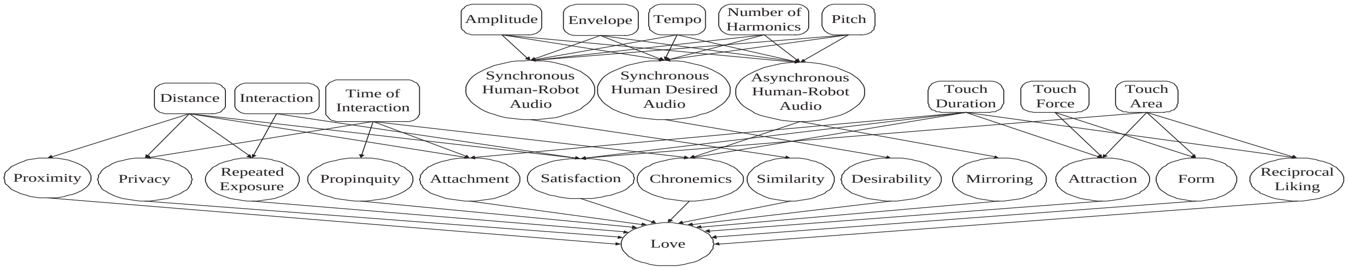

Fig. 2. The overview of the Bayesian Network for long-term love assembly module

IV. AFFECTIVE STATE TRANSITION

During interactions between the robot and the environment different emotions could be transferred from humans to the robot. Such transition can be modeled by mapping each interactive input to the combination of six basic emotional values over time: happiness, sadness, disgust, surprise, anger, and fear.

When the robot senses an interaction, it would utilize an embedded audio algorithm to analyze and break down the voice into its parametric values consisting of tempo, pitch, number of harmonics, envelope as well as amplitude. After this, the audio sample would be divided into frames and processed with a sampling rate of 16kHz. The real time flow of values will be sent to a Gaussian Mixture Model where matching and categorization is performed to match the audio to six basic emotions [27]. The data would then enter the affective state layer to be processed.

Furthermore, the robot itself is in one of the internal states at any time. The affective state of the robot at time t depends on its initial state plus the interaction result caused by the interaction input. In addition that result is affected by the internal situation of the robot. Affective state transition can be designed as an emotional model. Energy and tension are known to be the two principle parameters for representing the emotions of a human being [28], [29]. Based on this fact emotional categories can be mapped to arousal, valence, and stance dimensions in a robot [30].

We have considered the main two dimensions of emotion as Activation $\vec{Act}$ and Motivation $\vec{Mot}$ axes in the 2D affective state plane in order to develop a affective space. We have also considered the third dimension of this affective space to represent Sub-States via the $\vec{Sub}$ axis. This third axis is used to present rate of changes in the main two dimensions. Hence, the affective space of the robot is defined as a 3D cartesian coordinate system with axes: $[\vec{Act}, \vec{Mot}, \vec{Sub}]$.

Using the above affective space, we present a novel transition system which could handle the immediate emotional properties of the robot . This short-term emotional module cooperates with the long-term love assembly module to manage overall internal state of the robot.

In order to model the system to link interaction and affective states, the transition in the affective state space is formulated as below:

$$\vec{S}_{t_{Act,Mot,Sub}} = \vec{S}_{t-h} + \eta\vec{\Phi} + \beta\Gamma\vec{\Delta} \tag{14}$$

where $\vec{S}_t$ is the affective state of the agent in the affective space at time t and $\vec{S}_{t-h}$ is affective state in time $t-h$, where h is the sampling time.

$\vec{\Phi}$ is the vector field over the states which converges to a stable point in affective state coordinate system.

Vector $\vec{\Phi}$ can be considered as the gravitational field of a point mass c, located at point$P_0 \in \Re^3$ having position $r_0 \in \Re^3$ as:

$$\vec{\Phi} = \frac{-kc}{|\vec{r} - \vec{r}_0|}(\vec{r} - \vec{r}_0) \tag{15}$$

where $c, k \in \Re$ are constant numbers, $r, r_0 \in \Re^3$, $\vec{\Phi}$ points toward the point r_0 and has magnitude $|\Phi| = \frac{kc}{|\vec{r}-\vec{r}_0|^2}$.

η is the adjusting parameter for converging vector field.

β is the affective state coefficient which can be assigned to regulate rate of changes in the affective state.

Γ is the learning rate.

$\vec{\Delta} = \vec{\Delta}_{Act,Mot,Sub}$ is the 3D normal vector to transfer the state over time in the affective state space based on the emotional input according to interactions.

First two components are in the Activation - Motivation plane which are driven from emotional input:

$$\vec{\Delta}_{Act,Mot} = \sum_{m=1}^{6} e_{Mot_m}\vec{Mot} + \sum_{m=1}^{6} e_{Act_m}\vec{Act} \tag{16}$$

where $\vec{Mot}$ and $\vec{Act}$ are representation of Motivation and Activation axes in x and y directions in Cartesian coordinate system and vector e corresponds to the six values of the basic emotions, which are happiness, sadness, disgust, surprise, anger and fear, in Activation and Motivation directions.

The third component of $\vec{\Delta}$ represents the movement in the sub-state direction which obtained from the rate of the first two components:

$$\vec{\Delta}_{Sub} = |\frac{d}{dt}\vec{\Delta}_{Act,Mot}|\vec{Sub} \tag{17}$$

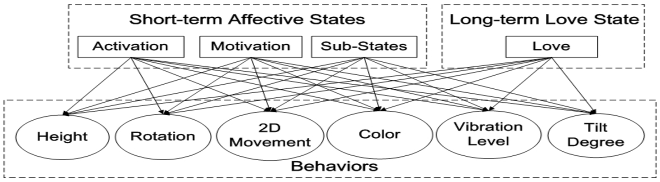

Fig. 3. Artificial Neural Network for controlling the behaviors of the robot via short and long term sentimental modules

where $\vec{Sub}$ is the representation of the sub-states axes in z direction in the Cartesian coordinate system. In this way the vector $\beta\Gamma\vec{\Delta}$ finds its direction to reach the next affective state.

Hence the overall affective state formula, considering the interaction and transition methodology, can be presented as:

$$\vec{S}_{t_{(Act,Mot,Sub)}} = \vec{S}_{t-h} + \eta\frac{kc}{|\vec{r}-\vec{r}_0|^2} + \beta\Gamma(\sum_{m=1}^{6} e_{mot_m}\vec{Mot} + \sum_{m=1}^{6} e_{act_m}\vec{Act} + |\frac{d}{dt}\Delta_{Act,Mot}|\vec{Sub}) \quad (18)$$

In this way, the short-term affective state of the robot can be generated for computing the immediate sentimental properties of the robot. Using this short-term affective property, the robot is capable of undergoing several affective states by employing the Affective State Transition module which handles transformations from one affective state to another. As presented in this Chapter, these transitions are based on previous states, current mood and interaction influences from the environment.

V. ROBOT'S BEHAVIOR

A two layer Multi-Layer Perceptron (MLP) as the form of the Artificial Neural Network can be employed to control robot's behavior. This MLP is presented in Figure 3. The robot's behaviors are generated via six main behavioral parameters including: tilt, vibration, color, movement (as navigation in two dimensional space), rotation and height. This MLP controls behaviors of the robot via connections with appropriate weights to the Love State Assembly module, which considered long term love parameters between human and robot to find the quantity of love as the outcome of the Bayesian network as presented in Chapter III, and the Affective State Transition module, which handles the immediate affective properties of the robot including activation, motivation and sub-State as illustrated in Chapter IV.

VI. IMPLEMENTATION

We have designed and developed a robot which is capable of audio and touch communication with humans as presented in Figure 4.

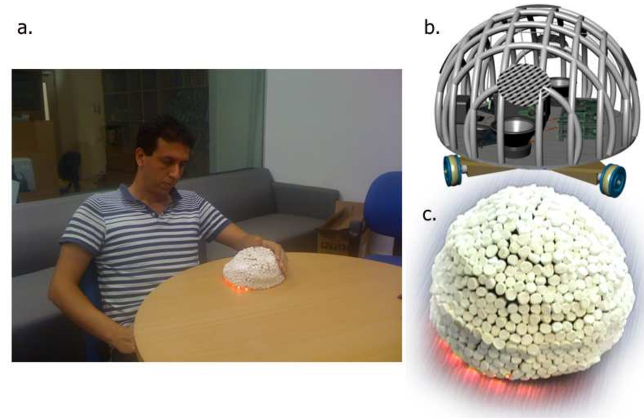

Fig. 4. a. A snapshot of the Human-Robot interaction b. Designed robot c. Developed robot

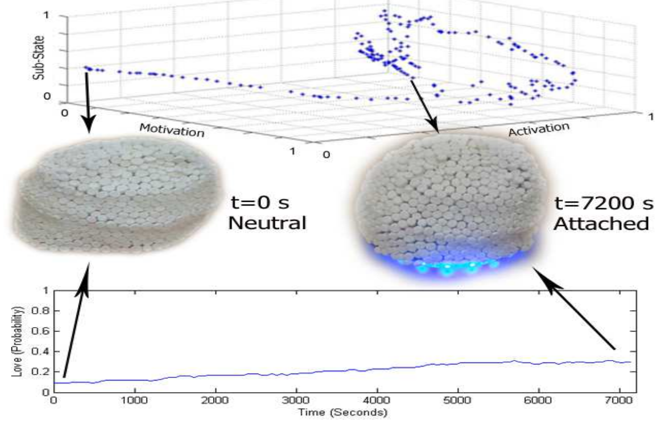

Fig. 5. Affective state transitions and love probabilities during two hours of interaction and robot's behavioral states at the beginning and end of the interaction

The affective state transitions and the output of the Bayesian Network for the Love Assembly module during two hours of human-robot interaction are presented in Figure 5 respectively. Also snapshots of the robot behavioral situation at the beginning and end of the experiment are illustrated according to the corresponding sentimental parameters.

In order to examine the effect of both short and long term sentimental parameters, we have tested the system with a user study. 8 person are asked to experience 5 different forms of interaction with the robot:

- In the static test the robot was placed in the environment without any movement.
- In the random test the robot was moving randomly in the environment without engaging sentimental modules.
- In the short-term effect test only the Affective State module was activated.
- In the long-term effect test only the Love Assembly

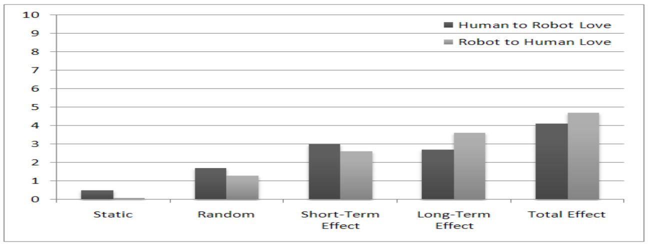

Fig. 6. Evaluation results of the human-robot love experiment

module was activated.
- In the total effect test all the sentimental modules of the robot were functioning.

We asked users to rate their experience between 0 and 10 based on the level of love and liking that they felt during the 2 hours of experiment with robot in two aspects:

- Human to Robot Love: Amount of love that the person felt about the robot.
- Robot to Human Love: Amount of love that the person felt that received from the robot.

The result of this user study is presented in Figure 6. Experiments show that the combination of both short and long term sentimental modules generates best bi-directional love between the human and the robot.

VII. CONCLUSION

Resembling human love, we presented a sentimental robotics system as Lovotics which consists of a coupled short and long term sentimental modules. This system considered both instantaneous and gradual effective parameters of developing close relationship between humans and robots.

VIII. ACKNOWLEDGMENTS

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References

[1] D. Sakamoto, T. Kanda, T. Ono, H. Ishiguro, and N. Hagita, "Android as a telecommunication medium with a human-like presence," in *Proceedings of the ACM/IEEE international conference on Human-robot interaction*. ACM, 2007, p. 200.

[2] T. Minato, Y. Yoshikawa, T. Noda, S. Ikemoto, H. Ishiguro, and M. Asada, "Cb2: A child robot with biomimetic body for cognitive developmental robotics," in *Proc. of IEEE/RAS 7th Int. Conference on Humanoid Robots*, 2007.

[3] M. Zecca, N. Endo, S. Momoki, K. Itoh, and A. Takanishi, "Design of the humanoid robot KOBIAN-preliminary analysis of facial and whole body emotion expression capabilities," in *8th IEEE-RAS International Conference on Humanoid Robots, 2008. Humanoids 2008*, 2008, pp. 487–492.

[4] N. Esau, B. Kleinjohann, L. Kleinjohann, and D. Stichling, "MEXI: Machine with Emotionally eXtended Intelligence–A software architecture for behavior based handling of emotions and drives," in *Proc. of Int. Conf. on Hybrid and Intelligent Systems (HIS)*. Citeseer, 2003.

[5] S. del Moral, D. Pardo, and C. Angulo, "Social Robot Paradigms: An Overview."

[6] C. Breazeal, *Designing sociable robots*. The MIT Press, 2004.

[7] R. Picard, *Affective computing*. The MIT Press, 2000.

[8] C. Elliott, J. Rickel, and J. Lester, "Lifelike pedagogical agents and affective computing: An exploratory synthesis," *Artificial Intelligence Today: Recent Trends and Developments*, vol. 1600, pp. 195–211, 1999.

[9] D. Levy, "The Ethical Treatment of Artificially Conscious Robots," *International Journal of Social Robotics*, vol. 1, no. 3, pp. 209–216, 2009.

[10] M. Decker, "'Can humans be replaced by autonomous robots? Ethical reflections in the framework of an interdisciplinary technology assessment," in *Proceedings of the IEEE-RAS International Conference on Robotics and Automation (ICRA 2007), Workshop on Roboethics, Rome, Italy,(April 10–14, 2007)*.

[11] M. Arbib and J. Fellous, "Emotions: from brain to robot," *Trends in cognitive sciences*, vol. 8, no. 12, pp. 554–561, 2004.

[12] T. Esch and G. Stefano, "The neurobiology of love," *Neuroendocrinology Letters*, vol. 26, no. 3, pp. 175–192, 2005.

[13] S. Zeki, "The neurobiology of love," *FEBS letters*, vol. 581, no. 14, pp. 2575–2579, 2007.

[14] D. Watt, "Social bonds and the nature of empathy," *Journal of Consciousness Studies, 12*, vol. 8, no. 10, pp. 185–209, 2005.

[15] K. Scherer, "Expression of emotion in voice and music," *Journal of Voice*, vol. 9, no. 3, pp. 235–248, 1995.

[16] J. Cahn, "The generation of affect in synthesized speech," *Journal of the American Voice I/O Society*, vol. 8, no. 1, pp. 1–1, 1990.

[17] A. Gallace and C. Spence, "The science of interpersonal touch: An overview," *Neuroscience and Biobehavioral Reviews*, vol. 34, no. 2, pp. 246–259, 2010.

[18] D. Levy, *Love+ Sex with Robots: The Evolution of Human-robot Relations*. Harper, 2007.

[19] E. T. Hall, *The Hidden Dimension*. Anchor, October 1990.

[20] A. Aron, D. Dutton, E. Aron, and A. Iverson, "Experiences of falling in love," *Journal of Social and Personal Relationships*, vol. 6, no. 3, p. 243, 1989.

[21] J. Tucker and S. Anders, "Adult attachment style and nonverbal closeness in dating couples," *Journal of Nonverbal Behavior*, vol. 22, no. 2, pp. 109–124, 1998.

[22] K. Brennan and P. Shaver, "Dimensions of adult attachment, affect regulation, and romantic relationship functioning," *Personality and Social Psychology Bulletin*, vol. 21, no. 3, p. 267, 1995.

[23] T. BRUNEAU, "Chronemics and the Verbal-Nonverbal Interface1," *The Relationship of verbal and nonverbal communication*, p. 101, 1980.

[24] H. Wallbott and K. Scherer, "Cues and channels in emotion recognition," *Journal of Personality and Social Psychology*, vol. 51, no. 4, pp. 690–699, 1986.

[25] K. Floyd, "All touches are not created equal: Effects of form and duration on observers' interpretations of an embrace," *Journal of Nonverbal Behavior*, vol. 23, no. 4, pp. 283–299, 1999.

[26] K. Grammer, K. Kruck, and M. Magnusson, "The courtship dance: Patterns of nonverbal synchronization in opposite-sex encounters," *Journal of Nonverbal Behavior*, vol. 22, no. 1, pp. 3–29, 1998.

[27] D. Neiberg, K. Elenius, and K. Laskowski, "Emotion recognition in spontaneous speech using GMMs," in *Ninth International Conference on Spoken Language Processing*. Citeseer, 2006.

[28] J. Russell, "A circumplex model of a ect," *Journal of Personality and Social Psychology*, vol. 39, no. 6, pp. 1161–1178, 1980.

[29] R. Thayer, *The biopsychology of mood and arousal*. Oxford University Press, USA, 1989.

[30] C. Breazeal, "Emotion and sociable humanoid robots," *International Journal of Human-Computer Studies*, vol. 59, no. 1-2, pp. 119–155, 2003.