Affective-Centered Design for Interactive Robots

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Abstract. We present a new paradigm for the design of interactive robots called affective-centered design. By drawing on the disciplines of human-computer interaction (HCI), affective computing, and human-robot interaction (HRI), we suggest techniques robot designers can use to help ensure interactions with their robots are of high affective quality, and thus more likely to be enjoyed and accepted by users.

Category: Position Paper (*P*)

1 INTRODUCTION

Each year, robots are entering domestic environments in greater and greater numbers. According to a 2007 report by the International Federation of Robotics, there were 3.4 million personal service robots in use worldwide in domestic settings. The report forecasts that this number is expected to increase by 4.6 million robots by 2012 [40]. These domestic robots are being used to serve as health aids and companions, help with household chores, and provide education and entertainment to their users.

The domestic robot user presents a unique challenge to robot designers. Elderly users are likely to be uncomfortable with domestic robots due to a lack of exposure to technology, disabled users might have difficulty using robots that do not provide interaction modalities that accommodate their needs, and people using robots for household chore assistance are unlikely to have much time to devote to learning to use complexly designed systems. One way to address some of these problems is to design robots that allow people the ability to interact with robots naturally.

Natural interaction means allowing people the ability to communicate with robots in ways similar to how they communicate with other people. This includes both verbal communication (speech and non-speech vocalization) and nonverbal communication (body gesture, gaze, movement, and facial expression). Most people are able to express themselves in this way and easily interpret such expressions in others. While people generally do not expect such ease of interaction with machines, evidence suggests having it would help improve user engagement with the robot [57]. Indeed, by taking advantage of these interactive modalities, robot designers can go a long way toward ensuring their robots are accepted.

Thus, we present a new paradigm for interactive robot design called affective-centered design, which we describe in Section 2. This paradigm draws on the fields of human-computer interaction (HCI), human-robot interaction (HRI), and affective computing. Our desired goal for presenting this paradigm is to help designers create a positive user experience by ensuring high affective quality of interaction with a robot.

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1.1 Affective quality

Before describing the concept of affective quality and how it relates to interactive robot design, it is important to explicitly define the concept of affect. Many researchers struggle with precisely defining words like "affect", "emotion" , and "mood", and rightfully so. The definitions of these words have become increasingly convoluted not only in vernacular English, but within scholarly literature as well. For the purposes of this paper, we shall adopt Clore and Palmer's stance which is to simply include these concept under the umbrella term "affective states." [2]. Thus, "affect" refers to "an embodied reaction of pleasure or displeasure signifying the goodness or badness of something.' A "psychological 'state' is assumed to exist whenever multiple systems of an organism reflect the same condition at the same time." For example, anger as an affective state might refer to both internal thoughts and feelings, as well as non-verbal expressions of anger (furrowed eyebrows, a raised voice, etc.) [10].

Affective quality is the "ability of an object or stimulus to cause changes in one's [affective state]" [67]. To call a human's interaction with a robot to be of "high affective quality" means that the overall affective state of the user is positive during the interaction. This is a qualitative yet objective assessment of interaction quality. As we will see in Section 4.1, HCI researchers have successfully used affective quality as a usability dimension when assessing systems. Thus, we believe it will also be useful as a usability dimension for interactive robots.

1.2 Implicit communication

Palen and Bødker [41] suggest that emotions should not be seen as simply a *feature* of interaction, but as an integral part of interaction itself. Thus, all interaction is emotional; even when it is emotionally neutral it is still framed by the idea of emotions. In some ways, emotions can be seen as a communication medium. Rani and Sarkar [43] describe this as "implicit communication", where a robot responds to the emotional state of a human (e.g., afraid, tired, happy) or simply to an emotionally neutral intention of a human (e.g., *Fetch me that object I'm pointing at*).

Implicit communication is an important line of research for interactive robot designers, because the ability for robots to fully understand explicit human communication (i.e., speech) is a long way off. While the natural-language processing community continues to advance the state-of-the-art in this area, roboticists can make huge strides forward by creating robots that understand at least rudimentary non-verbal behavior.

Communication is a two-way street, however. As Wallach and Allen point out, robots that interact with people in a social context

[2] Within this paper, if we use the words "emotion", "affect", or "mood", we always mean the umbrella term "affective states" as defined in Section 1.1.

should be able to gesture in a way that allows them to communicate their intentions [64]. This allows people the ability to understand a robot's capabilities and know what to expect. Cañamero and Gaussier [9] describe this in terms of a dichotomy between internal and external communication. Internal being the affective states the robot represents (including its representation of the emotional context outside itself) and external being the outward manifestation of emotion that the robot makes.

Thus, affective-centered design for interactive robots has two important aspects. There is affect recognition - *what is the human's affective state*? And affect generation - *how should the robot respond to that state and express itself appropriately?*

2 AFFECTIVE-CENTERED DESIGN

Affective-centered design is an iterative design process modeled somewhat after human-centered design. Human-centered design is an ISO standard that gives guidance throughout the entire design lifecycle of an interactive system. (See Figure 1). Some of its major tenets include:

- Involving end-users throughout the design lifecycle to ensure their needs are adequately addressed
- Understanding the context in which the system will be used
- Appropriately delegating function between the system and the user
- Adequately understanding the capabilities of both the system and the user
- Iterative design
- Multi-disciplinary design[53]

While this standard provides a general framework for interactive robot design, it does not provide practical guidelines that robot designers can employ. Furthermore, it does not consider affective quality whatsoever within the design process.

Therefore, in addition to the aforementioned tenets, the affective-centered design process also includes the following tenets, all of which can be employed iteratively throughout the design lifecycle of an interactive robot:

- Using affective quality as a metric throughout the design lifecycle
- Surveying the affective states of users
- Evaluating the affect generation of robots

We will now explain each of these tenets in detail. Later, in Section 3, we will describe a real-world example of how we employed the affective-centered design process in our own research. (Also, see Figure 2 for an illustration of the process.)

2.1 Affective quality throughout the entire lifecycle

In HCI, affective quality has been used successfully as an evaluative metric for interactive systems (See Section 4.1). And in HRI, several robots have been designed with user and/or robot affect in mind (See Section 4.3). However, a number of these projects examined human responses very late in the design lifecycle, often well after the systems had already been built. For 2D interactive systems this is somewhat acceptable, because it is relatively easy to change graphical-user interfaces. However, for robots, physical hardware changes are far more problematic. For example, if a humanoid robot is built with an extremely frightening face, no amount of behavioral changes to its affect generation software will change the fact that its physical

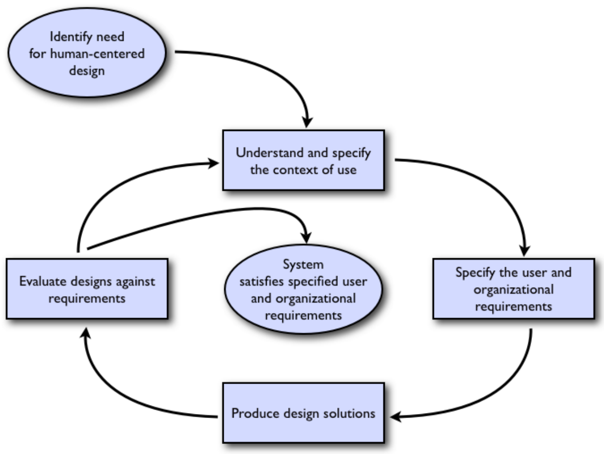

Figure 1. The human-centered design process for interactive systems. [23]

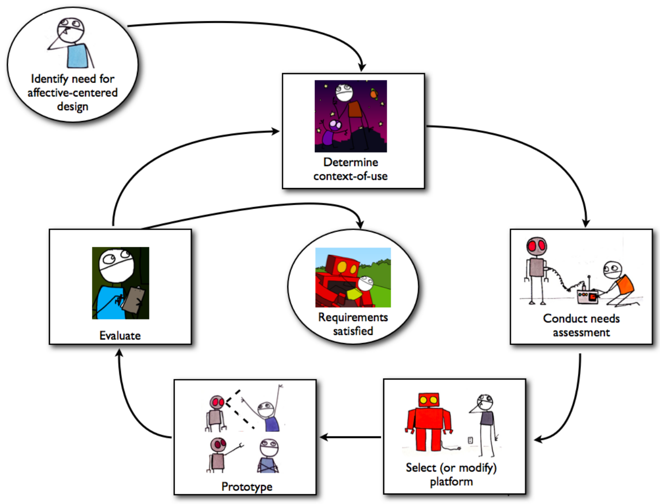

Figure 2. The affective-centered design process for interactive robots. Images by Sam Brown, explodingdog.

appearance is scary. Therefore, it is critical that interactive robot designers begin to present design ideas to users before a single wire is soldered, and continue to do so throughout the entire design lifecycle of the robot.

It is possible to present design ideas to users in an inexpensive way via paper prototypes, photographs, and simulation software. This need not be a formal usability study; it can be accomplished by talking to friends, colleagues, and family members. It is best to include at least some users from the population of people intended to interact with the robot, but this is not always possible. The most important thing is that representative users are included. For example, if one is designing a companion robot for the elderly, presenting design ideas to one's great aunt will yield far more informative results than solely presenting ideas to one's labmate.

If during the design process it becomes apparent that the affective quality of interacting with the robot is negative, it is important to identify why and figure out ways to mitigate it. Users are generally able to explicitly describe what they dislike about a robot, though it may require some in-depth interviewing to isolate the problem.

For example, we recently designed a empathetic conversation robot (described in Section 3) and ran a pilot study to evaluate it. After our study, we asked subjects how they felt about conversing with the robot. Here is an excerpt of one interview:

> **Experimenter**: How did you feel talking to the robot?
> **Subject:** Very weird. I've done voice recognition training, so I've talked to computers before. But [the robot] wasn't trying to make me feel anything. It was a weird experience.
> **Experimenter**: How was it weird?
> **Subject:** The reactions he had to what I was saying seemed to be negative.
> **Experimenter**: How so?
> **Subject:** He looked away from me at the start of the experiment. I would expect him to nod as if he was interested [in what I was saying], not look away.

While a user might give a terse reply, "It was a weird experience," by careful follow-up questioning it can quickly become clear what the problem is (in this case, poor gaze direction).

2.2 Surveying users' affective states

There are two primary ways to survey users' affective states during the interactive robot design lifecycle. The first is via a human experimenter who is in some way assessing a user. Such an assessment might be made using ethnographic observation [18], common ground analysis [58], embodiment analysis [12], questionnaires, interviews, or other techniques [19]. The goal of these techniques is to characterize the interaction with the robot in terms of people's attitudes toward it.

The second way is to perform automatic evaluation of users' affective states. This type of assessment is most likely to be performed by the robot itself, and will be used to modify its own behavior accordingly. We will describe this in more detail in Section 4.2.

Both of these affective state analyses are useful throughout the design lifecycle of an interactive robot. By understanding users' attitudes one can begin to characterize the quality of interaction, and modify the robot's design as necessary.

2.3 Evaluating affect generation of robots

The third tenet of affective-centered design concerns evaluating how the robot expresses affect. This measure is, of course, tightly coupled with how the user feels about the interaction. But this might also be something evaluated by robot designers independent of a user's reactions. For example, during a prototyping stage, certain behaviors might need be tweaked in order to produce the desired result.

A robot's affective state can be assessed on several levels, such as its contextual understanding of the world, the appropriateness of responses it gives, and the degree to which it expresses an affective state. To perform these assessments, robot designers can actually employ some of the same techniques as described in the Section 2.2, particularly ethnography and common-ground analysis. The difference is that the robot becomes the focus of evaluation, and its affective expression is what is measured.

3 AFFECTIVE-CENTERED DESIGN IN PRACTICE

To illustrate how robot designers can use affective-centered design in practice, we will briefly present our ongoing work on a conversational robot. In our work with this robot we have employed several elements of affective-centered design, such as understanding the context of use, carefully selecting our platform, performing design tradeoffs, running a pilot study, and iterating on Virgil's design accordingly.

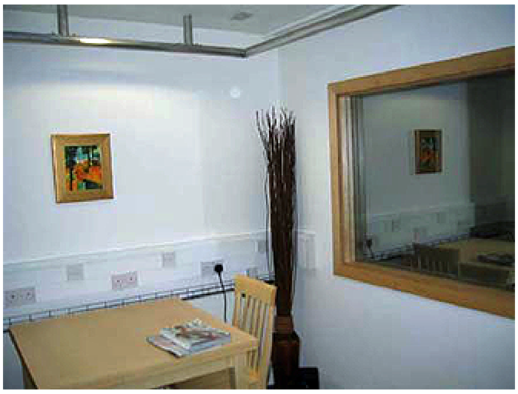

Figure 3. The Computer Laboratory usability lab.

3.1 Context of use

Before we began our research, we first considered the context of use for our robot. We were interested in creating an empathetic conversation partner capable of understanding some rudimentary affective states of humans and responding to them with appropriate affective expressions of its own.

Since the focus of our research is on empathy during one-on-one human conversations, we decided that the most appropriate physical space for users to interact with the robot would be in a home-like setting. Thus, we selected the Cambridge Computer Laboratory usability lab as the place to perform our initial studies. The usability lab is meant to resemble a living room - it has carpets, tables, chairs, and pictures on the wall. It also has a one-way mirror to allow for unobtrusive observation (See Figure 3).

3.2 Platform selection

While we ultimately would like to use an expressive humanoid head for our research, at present we are limited to inexpensive, off-the-shelf robots on which to try our ideas. The robot we selected is actually in some ways a prototype; by only costing $150 USD we are able to make initial strides forward in the behavioral design of an empathetic robot.

Thus we chose to begin our work on the robot Virgil, a chimpanzee robot made by WowWee. (See Figure 4). Virgil is a robot with 18 degrees-of-freedom (DOFs) in total. Its upper-lip has 2 DOFs (up/down), its lower jaw 2 DOFs (up/down), its eyes 4 DOFs (up/down/left/right), eyebrows 2 DOFs (up/dpwn), and its head 8 DOFs (roll/pitch/yaw). The robot can be operated via remote control and it also has some autonomous reactive behaviors, such as moving its head, opening and closing its mouth, and scrunching its nose [44].

3.3 Design tradeoff analysis

Since Virgil is intended to be a conversational robot, we initially wanted to have the robot speak. However, as we began working with

Figure 4. Virgil, our conversation robot.

the robot we quickly realized that performing speech-to-mouth syntonization is extremely difficult, and with a robot with only 4 DOFs in its lower face we realized it would be quite challenging to do a convincing job. As is well-documented in the psychology and animation literature, people are so sensitive to incongruous speech-face synchronization it can interfere with speech comprehension [33].

Thus, we decided it was better to have a silent robot than one that made people uncomfortable due to its strange mouth movements. Ironically this design tradeoff actually ended up lowering the affective quality of the robot in a way we had not predicted, as we will see in Section 3.4.

3.4 Pilot study

Early on in our design lifecycle, we wanted to explore the ideas of how non-verbal communicative gestures of empathy might alter people's affective states. So we ran a pilot study [44] with Virgil and a user interacting one-on-one in the usability lab. We asked all subjects to tell both a non-personal and personal story to the robot.

Our study had an experimental and control condition. In the test condition we wizard-of-oz controlled the robot to make empathetic head gestures (nodding) and mouth movements (open mouth in surprise). In the control condition, the robot acted autonomously in a random manner.

Following the study, we asked subjects to complete a written questionnaire that asked them to rate their interaction with the robot. These were 5-point Likert scale questions such as "I think Virgil could be a friend of mine," and "Virgil recognized my feelings and emotions appropriately for the situation". This resulted in each subject having an overall interaction satisfaction score. As we predicted, subjects in the experimental condition rated the interaction far more favorably than those in the testing condition [44].

We also asked subjects follow-up interview questions such as, "How did you feel talking to the robot?" and "Did you feel the robot was an amicable conversation partner?". Subjects made comments about the appearance of Virgil (ranging from neutral to negative), the appropriateness of responses it gave (people in the control condition made very negative remarks, while those in the experimental group were more positive), and communication flow. Most surprisingly, nearly every subject made strong statements that they wished the robot would make communicative noises or else spoke back. They said conversation was a two-way street, and one-sided conversations just did not feel natural to them [44].

This study was very helpful to us because it made us rethink several major design decisions, including our decision to have the robot be silent. Since we are in the early stages of our work we are fortunately able to modify the platform to accommodate these insights. We will then perform an additional pilot study to see if these design changes lead to an improved quality of interaction.

4 RELATED WORK

Since the goal of affective-centered design is to improve the affective quality of interaction with a robot, there are (at least) three primary fields that help to inform this design process. They are: human-computer interaction (HCI), affective computing, and human-robot interaction (HRI). This section provides a brief overview of relevant work done in these fields as they relate to affective-centered design for interactive robots. By no means is this section exhaustive, nor is it the case that these fields are mutually exclusive.

4.1 Human-computer interaction

In the field of HCI, a transition has begun to take place within the community from "human factors to human actors" [1]. In other words, researchers are considering people's emotional experience while interacting with a system as a new dimension of usability. Empirical research has shown that how people perceive the affective quality of a system positively impacts how they perceive its usability [11, 50, 59, 60, 67].

Norman has done pioneering work on the idea of using affective quality as a usability dimension. He suggests that when people "feel good" about a system they are more likely to overlook flaws in its design, find the system easier to learn, and also perform better when confronted with difficult tasks [36]. Later, Norman proposed a theoretical framework for three levels of emotional experience: Reflective, Behavioral, and Visceral.

- The reflective layer concerns "intellectually-induced reactions". So, in the example of product design, a Perrier label on a water bottle.
- The behavioral layer concerns "expectation-induced reactions". For example, the water inside a plastic bottle.
- The visceral layer concerns "perceptually-induced reactions". This would be, "a beautiful bottle that is used as a vase." [37, 38]

This framework has received recent empirical support by Lim et al. who found that the reflective layer was tightly coupled to peoples' experience of usefulness, as were the other layers. Thus, it is important for interactive products to have useful functionality. Furthermore, the researchers found that the overall quality of the interaction is critical to people's emotional experience [30].

This result has interesting design implications for interactive robots, because a robot's appearance might not be in concordance with its function or behavior [45]. For example, it may be difficult to initially identify a companion robot as a companion, whereas it is usually pretty easy to identify a telephone as a telephone. Thus, novel, interactive robots may need to present affective clues to users to appropriately advertise their function.

4.2 Affective computing

Affective computing is a discipline devoted to the idea of giving machines the ability to recognize and generate affect [42]. In some ways, the field exists to address the failings of traditional HCI systems, which typically neglect affective state changes in users. In fact, some argue that such neglect is a reason many users view interactions with computers as "cold, incompetent and socially inept." In order to address this, several leaders in the field have stated that it is critical that user interfaces of the future are able to "detect subtleties of and changes in the user's behavior, especially his/her affective behavior, and to initiate interactions based on this information rather than simply responding to the user's commands" [66].

Until recently, most of the approaches to affect recognition centered around posed data with exaggerated affective expressions, were limited to a small set of emotions (such as anger, fear, and happiness), and were restricted to single modes of expression (just face or just speech). However, the field is now shifting toward looking at recognizing, multi-modal, less-constrained naturalistic expressions [66]. For example, el Kaliouby and Robinson worked on the generalization of facial affect inference for complex mental states [14, 15, 16] while Sobol and Robinson worked on inferring affect from naturally-evoked speech [55, 56]. Bernhardt and Robinson worked on inferring affect from body posture and gesture [2].

As for affect generation (also called "emotion synthesis"), research into several affective channels of expression are being explored. These include facial animation [13], gestures [20], speech [51], nonverbal vocalizations, and others.

The field of affective computing is very relevant to interactive robot designers because the community has already begun to tackle a number of hard problems related to interacting in the physical world. Poor lighting, noisy environments, sensor fusion, widely varying communication styles, and other problems are also encountered in robotics.

4.3 Human-robot interaction

In the field of HRI, quite a number of interactive robots have been designed with affect in mind. Breazeal et al. [4] and Fong et al. [17] present thorough surveys of many such robots and their theoretical emotional underpinings. We will present a subset of these robots and introduce a few others using role categories suggested by Scholtz [52] and Goodrich and Schultz [19], as well as some general topic-area categories we've created. For each category we will list the names of representative robots and cite papers about them that give mention to the affective aspects of their design.[3] We will then highlight one robot and discuss how its design incorporates elements of affective-centered design. (The name of the highlighted robot will be italicized.)

4.3.1 Epigenetic (Developmental) Robots

Robots: Cog[49], HOAP-3[8], iCub[62], *Kismet[3]*, Leonardo[32]

A number of interactive robots have been created with some degree of affective understanding and generation capability using an epigenetic approach. This approach uses ideas from developmental psychology to help robots learn sophisticated social behaviors [48]. Many of these developmentally-based robots inherently take social context into account in order to learn to adapt to the humans interacting with them. One of the first of these robots is Kismet, an anthropomorphic, expressive robot designed entirely for emotional interaction with humans. By understanding the social cues of humans in the environment, Kismet is able to respond in an emotionally appropriate way to people [3]. Its thoughtful design has lead to it being a very well accepted and regarded robot.

4.3.2 Entertainment Robots

Robots: AIBO[24], ASIMO[35], *Keepon*[26], AUR[22], Improv Robots[6]

Kozima and Michalowski were interested in building a robot that could interact with children in a pleasant and natural way. Their first attempt was the Infanoid robot, which was a highly mechanical-looking, very expressive robot. From observational studies the researchers found that the appearance and behavior of this robot was overwhelming children. This insight led them to the successful design of the robot Keepon, which is a minimally-designed interactive dancing robot. The robot only has 4 degrees of freedom, but is easily able to express attention via head direction and emotion via rocking motions. Its design was well informed by observing hundreds of children interacting with the robot for over 400 hours in total [26].

4.3.3 Therapeutic Robots

Robots: Huggable[29], iCat[21], KASPAR[46], *PARO*[63], Shybot[28],

Shibata et al. describe their desire to build an affect robotic pet that was capable of sensing the emotions of the people it was interacting with and alter its affect accordingly [54]. Their design description indicates an implicit understanding of affective-centered design, because from the outset they concerned themselves with how their robot would interact emotionally with users, and tailored the robot's design accordingly. This mindset led the reearchers to later create the very successful implementation of PARO the robotic seal, which has been used effectively to reduce stress and depression among the elderly [63].

4.3.4 Peer Robots

Robots: Vikia[7], Robonaut[61], *Valerie* [25], GRACE[47], Mel [57]

Kirby et al. designed Valerie, a robot receptionist designed to facilitate long-term social interaction with people; the researchers wanted the robot to maintain people's interest over time [25]. The robot was thoughtfully designed in a way that employed elements of affective-centered design - the physical appearance of the robot, its station, and its behaviors were carefully considered to create an engaging experience with users. After several years of observations of people interacting with the robot, the researchers also realized ways to improve its design that were motivated by the emotional state of users [47].

4.3.5 Mentor Robots

Robots: *Basketball Coach* [31], Chips[39], RoCo[5]

Liu et al. describe a robotic basketball coach that monitored the physiological signals (heartrate and galvanic skin response) of people while they shot baskets. Depending on how anxious people seemed to be, the robot altered the game's level of difficulty. The researchers found through this style of interactive teaching people's performance improved [31]. This design is very much affective-centered within the context of a closed loop system. However, it's worth noting that

[3] This listing is by no means exhaustive, nor are these categories mutually exclusive.

requiring people to wear sensors is often undesirable due to problems with affixing sensors to the skin via abrasive gels, calibration problems, and the hardware being seen as obtrusive [65]. Therefore, having users endure such issues might not outweigh the benefit of having robots "in the know" about people's physiology. This sort of decision making is part of the tradeoff analysis phase that needs to be considered during the affective-centered design process.

4.3.6 Industrial Robots

Robots: *Safety Arm*[27], WE-4R Arm [34]

One normally would not expect designers of industrial robots to need to consider affect in their design; however, those that work near humans may very well need to be aware of their surrounding social context. For example, Kulic and Croft describe using affect recognition in an interactive scenario where an industrial robotic arm and a human are working together. The robot is made aware of the user's affective state (in response to its motions), and uses this information to calculate a "danger index", thus modifying its behavior accordingly [27]. This sort of thinking is also employing elements of affective-centered design - the researchers knew that industrial robots working with humans involve safety risks, and it would be helpful if such robots could quickly understand when their human peers feel afraid so that they do not endanger them.

The aforementioned work in HRI helps illustrate the value of using affective-centered design practices when designing interactive robots. By considering the affective states of users as well as the affect generation capabilities of robots, robot designers are helping to ensure their robots will be well-accepted and understood by people.

5 DISCUSSION

We introduced affective-centered design, which is a new process for the design of interactive robots. The motivation behind such an process is to give robot designers techniques for ensuring that interaction with their robots is of high affective quality, meaning that the overall affective state of the user is positive during the interaction. This will hopefully help ensure more people are accepting of robots in domestic environments.

The major tenets of affective-centered design are very similar to human-centered design, where one takes time to understand the robot's context of use by involving representative users throughout the design lifecycle and performing iterative, multi-disciplinary design. This is accomplished by using affective quality as an evaluative measure, through both surveying the affective states of users and evaluating the affect generation capability of robots. We demonstrated how one might go about this process in practice by discussing how we developed the conversational robot Virgil.

Affective-centered design is a process that sits at the intersection of three fields - HCI, affective computing, and HRI. These fields are all interested in ensuring technology is well accepted by end-users; thus, by examining affect as a quality of interaction with robots, we hope the affective-centered design process will prove helpful to researchers in each of these fields.

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REFERENCES

[1] L. Bannon, 'From human factors to human actors: the role of psychology and human-computer interaction studies in system design', in *Design at work: cooperative design of computer systems*, eds., J. Greenbaum and M. Kyng, 25–44, L. Erlbaum Associates Inc., Hillsdale, NJ, USA, (1992).

[2] D. Bernhardt and P. Robinson, 'Detecting affect from non-stylised body motions', in *Proc. of the 2nd international conference on Affective Computing and Intelligent Interaction (ACII)*. Springer-Verlag, (2007).

[3] C. Breazeal, *Designing Sociable Robots*, MIT Press, Cambridge, MA, USA, 2002.

[4] C. Breazeal, A. Takanishi, and T. Kobayashi, 'Social robots that interact with people', in *Springer Handbook of Robotics*, eds., B. Siciliano and O. Khatib, 1349–1369, Springer, (2008).

[5] C. Breazeal, A. Wang, and R. Picard, 'Experiments with a robotic computer: body, affect and cognition interactions', in *Proc. of the ACM/IEEE international conference on Human-robot interaction (HRI)*, pp. 153–160, Arlington, Virginia, USA, (2007). ACM.

[6] A. Bruce, J. Knight, S. Listopad, B. Magerko, and I. R. Nourbakhsh, 'Robot improv: using drama to create believable agents', in *Proc. International Conference on Robotics and Automation (ICRA)*, (2000).

[7] A. Bruce, I. Nourbakhsh, and R. Simmons, 'The role of expressiveness and attention in human-robot interaction', in *Proc. IEEE International Conference onRobotics and Automation (ICRA)*, (2002).

[8] S. Calinon and A. Billard, 'A framework integrating statistical and social cues to teach a humanoid robot new skills', in *Proc. IEEE Intl Conf. on Robotics and Automation (ICRA), Workshop on Social Interaction with Intelligent Indoor Robots*, (May 2008).

[9] L. Canamero and P. Gaussier, 'Emotion understanding: Robots as tools and models', in *Emotional development: Recent research advances*, eds., J. Nadel and D. Muir, 235–258, Oxford University Press, New York, NY, (2005).

[10] G. L. Clore and J. Palmer, 'Affective guidance of intelligent agents: How emotion controls cognition', *Cognitive Systems Research*, **10**(1), 21 – 30, (2009).

[11] A. Crystal and S. Kalyanaraman, 'Usability, cognition, and affect in web interfaces: The role of informative feedback and descriptive labeling', in *International Communication Association*, (2004).

[12] K. Dautenhahn, B. Ogden, and T. Quick, 'From embodied to socially embedded agents - implications for interaction-aware robots', *Cognitive Systems Research, Special issue on Situated and Embodied Cognition*, **3**(3), 397–428, (2002).

[13] Z. Deng and J. Y. Noh, 'Computer facial animation: A survey', in *Data-Driven 3D Facial Animation*, Springer, (2007).

[14] R. el Kaliouby, *Mind-reading Machines: the automated inference of complex mental states from video*, Ph.D. dissertation, Computer Laboratory, University of Cambridge, 2005.

[15] R. el Kaliouby and P. Robinson, 'Generalization of a vision-based computational model of mind-reading.', in *In Proc. International Conference on Affective Computing and Intelligent Interaction*, eds., J. Tao, T. Tan, and R. W. Picard, volume 3784 of *Lecture Notes in Computer Science*, pp. 582–589. Springer, (2005).

[16] R. el Kaliouby and P. Robinson, 'Real-time inference of complex mental states from facial expressions and head gestures', in *Real-time Vision for Human-Computer Interaction*, 181–200, Springer, (2005).

[17] T. Fong, I. Nourbakhsh, and K. Dautenhahn, 'A survey of socially interactive robots', *Robotics and Autonomous Systems*, **42**, 143–166, (March 2003).

[18] J. Forlizzi, 'How robotic products become social products: an ethnographic study of cleaning in the home', in *Proc. of the ACM/IEEE international conference on Human-robot interaction*, pp. 129–136, New York, NY, USA, (2007). ACM.

[19] M. A. Goodrich and A. C. Schultz, 'Human-robot interaction: a survey', *Foundations and Trends Human-Compututer Interactaction*, **1**(3), 203–275, (2007).

[20] B. Hartmann, M. Mancini, and C. Pelachaud, 'Implementing expressive gesture synthesis for embodied conversational agents', *Gesture in Human-Computer Interaction and Simulation*, 188–199, (2006).

[21] M. Heerink, B. Krose, B. Wielinga, and V. Evers, 'Enjoyment intention to use and actual use of a conversational robot by elderly people', in *Proceedings of the 3rd ACM/IEEE international conference on Human robot interaction (HRI 08)*, pp. 113–120, New York, NY, USA, (2008). ACM.

[22] G. Hoffman, R. Kubat, and C. Breazeal, 'A hybrid control system for puppeteering a live robotic stage actor', in *The 17th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*, (Aug. 2008).

[23] ISO/IEC, '13407 Human-centred design processes for interactive systems', Technical report, ISO/IEC, (1999).

[24] P.H. Kahn Jr., B. Friedman, D. R. Perez-Granados, and N. G. Freier, 'Robotic pets in the lives of preschool children', in *CHI '04 extended abstracts on Human factors in computing systems*, pp. 1449–1452, New York, NY, USA, (2004). ACM.

[25] R. Kirby, F. Broz, J. Forlizzi, M. P. Michalowski, A. Mundell, S. Rosenthal, B. P. Sellner, R. Simmons, K. Snipes, A. Schultz, and J. Wang, 'Designing robots for long-term social interaction', in *Proc. of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 2199 – 2204. IEEE, (August 2005).

[26] H. Kozima, M. Michalowski, and C. Nakagawa, 'Keepon: A playful robot for research, therapy, and entertainment', *International Journal of Social Robotics*, (2008).

[27] D. Kulic and E. A. Croft, 'Affective state estimation for humanrobot interaction', *Robotics, IEEE Transactions on*, **23**(5), 991–1000, (2007).

[28] C. J. Lee, K. Kim, C. Breazeal, and R. Picard, 'Shybot: friend-stranger interaction for children living with autism', in *CHI '08 extended abstracts on Human factors in computing systems*, pp. 3375–3380, Florence, Italy, (2008). ACM.

[29] J. K. Lee, R. L. Toscano, W. D. Stiehl, and C. Breazeal, 'The design of a semi-autonomous robot avatar for family communication and education', in *The 17th International Symposium on Robot and Human Interactive Communication (RO-MAN 08)*, pp. 166–173. IEEE, (2008).

[30] Y. Lim, J. Donaldson, H. Jung, B. Kunz, D. Royer, S. Ramalingam, S. Thirumaran, and E. Stolterman, 'Emotional experience and interaction design', in *Affect and Emotion in Human-Computer Interaction: From Theory to Applications*, eds., C. Peter and R. Beale, 116–129, Springer-Verlag, Berlin, Heidelberg, (2008).

[31] C. Liu, P. Rani, and N. Sarkar, 'Human-robot interaction using affective cues', in *Proc. of the 15th International Symposium on Robot and Human Interactive Communication (RO-MAN)*. IEEE, (September 2006).

[32] A. Lockerd and C. Breazeal, 'Tutelage and socially guided robot learning', *Proc. of IEEE/RSJ International Conference on Intelligent Robots and Systems, (IROS).*, **4**, 3475–3480 vol.4, (2004).

[33] H. Mcgurk and J. Macdonald, 'Hearing lips and seeing voices', *Nature*, **264**(5588), 746–748, (December 1976).

[34] H. Miwa, K. Itoh, D. Ito, H. Takanobu, and A. Takanishi, 'Design and control of 9-dofs emotion expression humanoid arm', in *Proceedings of the 2004 IEEE International Conference on Robotics and Automation (ICRA)*, pp. 128–133. IEEE, (2004).

[35] B. Mutlu, J. Forlizzi, and J. Hodgins, 'A storytelling robot: Modeling and evaluation of human-like gaze behavior', in *Proc. International Conference on Humanoid Robots*. IEEE, (December 2006).

[36] D. A. Norman, 'Emotion & design: attractive things work better', *Interactions*, **9**(4), 36–42, (2002).

[37] D. A. Norman, *Emotional Design: Why We Love (or Hate) Everyday Things*, Basic Books, May 2005.

[38] D. A. Norman, A. Ortony, and D. M. Russell, 'Affect and machine design: Lessons for the development of autonomous machines', *IBM Syst. J.*, **42**(1), 38–44, (2003).

[39] I.R. Nourbakhsh, C. Kunz, and T. Willeke, 'The mobot museum robot installations: a five year experiment', in *Proc. IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, (2003).

[40] International Federation of Robotics, 'World robotics 2008: Statistics, market analysis, forecasts, case studies, and profitability of robot investment', Technical report, International Federation of Robotics Statistical Department, (October 2008).

[41] L. Palen and S. Bødker, 'Don't get emotional', in *Affect and Emotion in Human-Computer Interaction: From Theory to Applications*, Lecture Notes in Computer Science (LNCS), 12–22, Springer-Verlag, Berlin, Heidelberg, (2008).

[42] R. Picard, *Affective Computing*, MIT Press, 1997.

[43] P. Rani and N. Sarkar, 'Emotion-sensitive robots - a new paradigm for human-robot interaction', in *Proc. of the IEEE-RAS/RSJ International Conference on Humanoid Robots (Humanoids 04)*, pp. 10–12, (2004).

[44] L. D. Riek and P. Robinson, 'Real-time empathy: Facial mimicry on a robot', in *Workshop on Affective Interaction in Natural Environments (AFFINE) at the International ACM Conference on Multimodal Interfaces (ICMI 08)*. ACM, (2008).

[45] L. D. Riek and P. Robinson, 'Robot, rabbit, or red herring? Societal acceptance as a function of classification ease', in *17th International IEEE Symposium on Robot and Human Interactive Communication (RO-MAN 2008) Workshop on Robots as Social Actors*. IEEE, (2008).

[46] B Robins, K. Dautenhahn, R te Boekhorst, and C. L. Nehaniv, 'Behaviour delay and robot expressiveness in child-robot interactions: a user study on interaction kinesics', in *HRI '08: Proceedings of the 3rd ACM/IEEE international conference on Human robot interaction*, pp. 17–24, New York, NY, USA, (2008). ACM.

[47] S. Sabanovic, M. Michalowski, and R. Simmons, 'Robots in the wild: observing human-robot social interaction outside the lab', in *Proceedings of the 9th International Workshop on Advanced Motion Control (AMC 2006)*, pp. 596 – 601. IEEE, (March 2006).

[48] B. Scassellati, 'Building behaviors developmentally: A new formalism', in *1998 AAAI Spring Symposium "Integrating Robotics Research"*. AAAI, (1998).

[49] B. Scassellati, 'Theory of mind for a humanoid robot', *Auton. Robots*, **12**(1), 13–24, (2002).

[50] B. N. Schenkman and F. U. Jonsson, 'Aesthetics and preferences of web pages', *Behaviour & Information Technology*, **19**(5), 367–377, (2000).

[51] K. R. Scherer, 'Vocal communication of emotion: A review of research paradigms', *Speech Communication*, **40**, 227–256, (2003).

[52] J. Scholtz, M. Theofanos, and B. Antonishek, 'Theory and evaluation of human robot interactions', in *36th International Conference on Systems Sciences*. IEEE, (2003).

[53] H. Sharp, Y. Rogers, and J. Preece, *Interaction Design: Beyond Human Computer Interaction*, Wiley, March 2007.

[54] T. Shibata, M. Yoshida, and J. Yamato, 'Artificial emotional creature for human-machine interaction', *Systems, Man, and Cybernetics, 1997. 'Computational Cybernetics and Simulation'., 1997 IEEE International Conference on*, **3**, 2269–2274 vol.3, (Oct 1997).

[55] T. S. Shikler, *Le ton fait la musique - Analysis of expressions in speech*, Ph.D. dissertation, University of Cambridge, 2007.

[56] T. S. Shikler and P. Robinson, 'Recognising emotion in speech for human-computer interaction', in *International Workshop on Universal Access and Assistive Technology*, pp. 153–162, (March 2004).

[57] C. L. Sidner, C. Lee, C. D. Kidd, N. Lesh, and C. Rich, 'Explorations in engagement for humans and robots', *Artif. Intell.*, **166**(1-2), (2005).

[58] K. Stubbs, P. J. Hinds, and D. Wettergreen, 'Autonomy and common ground in human-robot interaction: A field study', *IEEE Intelligent Systems*, **22**(2), 42–50, (2007).

[59] M. Thuring and S. Mahlke, 'Usability, aesthetics and emotions in humantechnology interaction', *International Journal of Psychology*, **42**(4), 253–264, (August 2007).

[60] N. Tractinsky, A. S. Katz, and D. Ikar, 'What is beautiful is usable', *Interacting with Computers*, **13**, 127–145, (2000).

[61] G. Trafton, N. Cassimatis, M. Bugajska, D. Brock, F. Mintz, and A. Schultz, 'Enabling Effective Human-Robot Interaction Using Perspective-Taking in Robots', *IEEE Transactions on Systems, Man, and Cybernetics*, **35**(4), (2005).

[62] D. Vernon, G. Metta, and G. Sandini, 'The icub cognitive architecture: Interactive development in a humanoid robot', in *6th International Conference on Development and Learning (ICDL)*. IEEE, (July 2007).

[63] K. Wada and T. Shibata, 'Living with seal robotsits sociopsychological and physiological influences on the elderly at a care house', *IEEE Transactions on Robotics*, **23**(5), 972–980, (Oct. 2007).

[64] W. Wallach and C. Allen, *Moral Machines: Teaching Robots Right from Wrong*, Oxford University Press, 2008.

[65] R. D. Ward and P. H. Marsden, 'Affective computing: problems, reactions and intentions', *Interacting with Computers*, **16**(4), 707–713, (August 2004).

[66] Z. Zeng, M. Pantic, G. Roisman, and T. Huang, 'A survey of affect recognition methods: Audio, visual, and spontaneous expressions', *IEEE Transactions on Pattern Analysis and Machine Intelligence*, **31**(1), 39–58, (January 2009).

[67] P. Zhang and N. Li, 'The importance of affective quality', *Communications of the ACM*, **48**(9), 105–108, (2005).