Introduction to the Special Issue on "Designing the Robot Body: Critical Perspectives on Affective Embodied Interaction"

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1 INTRODUCTION

Designing and evaluating the affectivity of the robot body has become a frontier topic in **Human-Robot Interaction (HRI)**, with previous studies [1, 2] emphasizing the importance of robot embodiment for human-robot communication. In particular, there is growing interest in how the tactile, haptic materiality of the robot influences and mediates users' affective and emotional states. Indeed, the sheer physicality of robotic systems is a crucial factor in the morphology of the robotic platform, and therefore in the robot's appearance to the user. How do the tactile properties of materials subtly influence user interaction? Why do certain morphologies prompt more empathetic interactions than others? How is nonverbal communication affected through the coordination of movements of the torso, head, and appendages to provide more naturalistic-seeming interaction? What is the role of nonverbal communication in the production of artificial empathy? And how do such factors encourage trust and foster confidence for nonexpert users to interact in the first place? This recognition of machinic corporeality has been of practical interest to designers and engineers working across a range of robot forms and functions.

The objective of this special issue is to further this discussion, to consider theoretical, ethical, empirical, and methodological questions related to the design of robotic bodies in the context of affective HRI, and thus foster cross currents among engineering, design, social science, and artistic communities. It originally emerged as a set of conceptual and practical questions from a workshop at the 2020 ACM/IEEE International Conference on Human-Robot Interaction (HRI'20) in Cambridge, UK, co-organized by two of the editors [3]. The workshop, like so many other events, was canceled because of the restrictions of the COVID-19 pandemic. Consequently, we tried to

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pursue a longer-term exchange of engineering, design, and conceptual considerations through the publication of this special issue. Building out from the more practically minded exchanges of an in-person workshop, here was an opportunity to invite more wide-ranging contributions to consider questions related to the design of robotic bodies in the context of affective HRI. The issue could thus explore topics bridging embodiment and affect, including touch, materials, and physical form from the points of view of artists, designers, engineers, and social scientists alike.

With this wider focus across design and engineering, and into art and the social sciences, this special issue offers an opportunity for the robotics community to glimpse some of the related concepts and debates in the humanities and social sciences. Ever since the notorious work of psychologist Harry Harlow in his primate laboratory at the University of Wisconsin–Madison in the 1950s, the physical embodiment of the mother and the need for social bonding as well as physical sustenance has been recognized as a significant factor in the formation of healthy social and emotional relationships [4]. There is a perceptible difference to a socially isolated infant primate kept in captivity whether, when exposed temporarily to a mother figure, that figure is a real, breathing primate, a representation of the mother with an artificial head and wireframe body, or an artificial head, wireframe body crudely covered in toweling. The lesson here is that unlike software-based forms of artificial intelligence, the physical embodiment of a social robot is inescapably part of the equation for a human user. How the robot appears, and how it materially interacts with nonexpert users, especially those who are in social isolation for whatever reason, is going to be a crucial part of future HRI design.

In the wake of this basic issue of embodiment, there are theoretical and political concerns being raised that prompt urgent consideration of race and gender in body morphologies. Anthropomorphic social robots in particular coalesce into what Rhee [5] calls historical "imaginaries" of the robot as gendered, raced, and dehumanized labor. Social robots shift the focus from industrial labor to forms of emotional labor that Rhee argues "normalizes whiteness" (p. 105) and essentializes gender roles. This is a separate but related issue to the way that implicit gender and racial bias is perpetuated and encoded in artificial intelligence. Racial bias in robotics is beginning to be addressed (e.g., the "Black in Robotics" and "Black in Computing" initiatives). The gender bias in robotics is also beginning to be addressed [6, 7]. How robots "became" white (and, mostly, female) remains one of the most significant cultural-historical questions.

Along with embodiment are questions of affect and affectivity. The past two decades have featured what has become known as the "Affective Turn" in the humanities and social sciences that recognizes the role of affect and, to a lesser extent, embodiment in the production of intersubjective sociality. Psychological science interprets affect according to a straightforward coding system, such as the Facial Action Coding System (FACS) of Ekman and Friesen [8], where various Action Units are parsed through machine vision into discrete emotions such as fear, disgust, or surprise. Likewise, in a recent introductory textbook on HRI, Bartneck et al. [9] describe affect in this way:

> Affect is used as a comprehensive term that encompasses the entire spectrum of emotionally laden responses, ranging from quick and sub-conscious responses caused by an external event to complex moods, such as love, that linger for longer (e.g., Lang et al., 1997; Bonanno et al., 2008; Beedie et al., 2005). Within affect, a distinction is made between *emotions* and *moods*. [emphasis added]

Meanwhile the "affect" of the Affective Turn is less concrete and less discrete, something derived from the philosophy of Baruch Spinoza and Gilles Deleuze. Affect from this conceptual branching, such as the work from Massumi [10], problematizes traditional boundaries between sensations and affects, or cognitive and visceral experiences, is more social and collective, and is immediately interpreted by the subject as a series of intensities before becoming recognized and parceled out consciously as any type of emotion [11]. The point here is that affect is not something simply to be measured through an instrument, but something that is routinely subjectively felt in human-human interactions, and will also need to be considered in human-machine interactions. In his work on "affective grounding," Malte Jung is one of the few researchers in HRI who attempts such a broadening of scope by arguing for a focus on *shared understanding* rather than *expression* or *perception* as the basis for human-robot affective interaction. We can further ask: How do humanoid and zoomorphic robots complicate or disrupt these patterns of interaction? What interaction protocols can be used or developed to make HRI more accessible and inviting to users? How important is context of use to building affective relationships with robots? The significant challenge here is something that lies at the heart of this nonscientific formulation of affect: human subjects are irrational, they are allowed to be afraid, and trustful interaction takes time to establish. What practically can roboticists do about this?

Issues of embodiment have, of course, been addressed previously in the HRI literature. The inaugural HRI conference in 2006 in fact featured a keynote from Nass entitled "Every Body Is Somebody: The Psychology and Design of Embodiment" [12], which questioned how robot embodiment affected users' conception of, and response to, robots. In 2012, one of the editors of this issue, Guy Hoffman, argued for "embodied cognition" in HRI [13]. Researchers in HRI have explored the materiality of robots in the form of tactile robot skins [14] and handshakes [15]. Hu and Hoffman [16] have evaluated the capacity of skin texture change in a robot to convey robot emotions, instead of relying on gestures or facial expressions. "Leveraging Robot Embodiment to Facilitate Trust and Smoothness" by Reig et al. [17] sought to understand the role of robot embodiment in social interactions, particularly how robot embodiment influences users' trust and comfort. The 2018 paper of Hoffman and Bock, "The Peculiarities of Robot Embodiment (EmCorp-Scale)" [18], quantitatively demonstrated that users' perceptions of an artificial entity's physical capabilities were thoroughly influenced by robot embodiment. Soft robotic interfaces have shown promising potential for delivering sensorial quality of affective touch [19]. Questions of touch and affect in particular have been the main topic for HRI workshops such as "Advances in Tactile Sensing and Touch HRI" (HRI'12) [20] and "Applications for Emotional Robots" (HRI'14) [21].

However, as far as we are aware, this is the first special issue to bring together works that explicitly focus on the relationship between affect and embodiment in HRI, and for this we wished to integrate knowledge of embodiment and affect from across the fields of design, engineering, the social sciences, and the humanities in HRI. To this end, we set three overall objectives: first, from the world of design, to identify relevant questions for the design of robotic bodies with high affective qualities; second, from a more cross-disciplinary perspective, to consider cross currents in ethical, philosophical, and methodological questions in studying emotional relations between humans and robots; and third, and more generally, to use this special issue as a collective resource to foster synergies among artists, designers, engineers, and social scientists in affective robotics.

2 THE PAPERS AND ARTICLES

This special issue has four "Perspectives" papers and 10 research articles. The former are more speculative thinkpieces, shorter than research articles, designed to offer an overview of a particular area and its challenges in terms of affect and robot embodiment. The research articles are more conventional in terms of length and style. In the remainder of this special issue introduction, brief synopses of each of the works are offered, charting a healthy range of conceptual and methodological approaches to the topic, and also revealing some helpful thematic connections around touch, skin, body design, and embodied communication between some of them.

First, the Perspectives papers. Jonas Jorgensen's "Towards a Soft Science of Soft Robots: A Call for a Place for Aesthetics in Soft Robotics Research" investigates soft robotics as "a profoundly novel robot aesthetic" rather than a novel technical solution to automation of labor. Jorgensen argues that to create technologies fitting for embodied and affective engagement with humans, the current repertoire of soft robotics research needs to be expanded, from an approach focused on functionality and efficiency to include aesthetic practices and art-based methodologies. Mark Paterson's "Inviting Robot Touch (by Design)" asks why the basics of touch interaction with robot platforms is initially off-putting or uninviting for many users. This will be increasingly a problem for social robots as they develop, and especially socially assistive robotics, as this and a related article detail [22]. Paterson divides the problems into two categories. The first is "haptic loops" within engineering, where problems with haptic feedback in human-computer interaction follow across into HRI to a certain extent, and which offer qualitatively different forms of touching than more embodied forms of perception allow. The second category is "affective loops," which follows on from this embodied perspective, where a more holistically embodied form of touch is simply not met by current robotics, although a short genealogy of affective touching robots is offered. Erik Lagerstedt's "Multiple Roles of Multimodality Among Interacting Agents" brings attention to an important challenge in social robotics research, namely that discrepancies in terminology, assumptions, and perspectives can create negative barriers in interdisciplinary design teams. Taking the word "multimodality" for example, the paper calls for a pragmatic and pluralistic approach where the meaning of terms are explicitly negotiated among collaborators for each specific case while acknowledging the value of differences in definitions in different fields. The final 'Perspectives' piece by Katherine Harrison and Ericka Johnson, 'Affective corners as a problematic for design interactions', is a neatly-written provocation for interaction designers. Starting with the mundane robotics of their robot lawnmower and robot vacuum cleaner, and then broadening to more fully social and supposedly affective robots like Pepper, their paper demonstrates the difficulties and subsequent adaptations involved when human users have to deal with these devices 'in the wild' in their homes and gardens. There is, in other words, a gap between the robots as intentionally designed and the socio-technical limitations of companion robots that users must respond to, exemplified in the way robots sometimes go into unreachable corners or become unresponsive. Hence Harrison and Johnson's metaphor for interaction design of 'affective corners' is widely applicable, and also speaks to a Science and Technology Studies (STS) literature.

The Perspectives papers are followed by the longer research articles. Alexis Block and her team's "In the Arms of a Robot: Designing Autonomous Hugging Robots with Intra-Hug Gestures" is a comprehensive and in-depth look at their investigations with HuggieBot 3.0, which collects data from user interactions and enables it to perform what they call "robot-initiated intra-hug gestures." HuggieBot 3.0 is itself an adaptation from Block and Kuchenbecker's previous platform HuggieBot 2.0, which combined a custom sensing system with the Willow Garage PR2 and Kinova JACO arms. Their article starts from the position of the necessity of social touch that Paterson (mentioned previously) also refers to. From a real-world validation study, they develop a series of design guidelines for hugging robots whose validity extends beyond their own particular platform and user testing scenario. Both quantitative and qualitative data were gathered from user testing, all showing how astonishingly complex it is to engineer a prolonged hug interaction with a machine.

Just like in human-human interaction, they find that user evaluations point to the difficulties of initiating, and then ensuring, a "consensual and synchronous hugging experience" through responding rapidly to intra-hug gestures from the user. Although the future of a fully autonomous hug-generating robot remains on the horizon, the possibilities for custom hugs based on recognizing users is much closer, and the utility of these extended proxemic interactions with older adult users in particular is suggested. The guidelines, iteratively derived from user evaluations from this and the previous generation of HuggieBot, are also applicable more generally to proxemic interactions between humans and robots.

Edmund Barker and Carey Jewitt's "Collaborative Robots and Tangled Passages of Tactile-Affects" is a detailed ethnographic study of collaborative robots "in the wild" within an industrialized setting—a hot and noisy glass factory. What is particularly noteworthy about their article is not just the ethnographic detail, based on on-site participant observation, visual records, and extensive interviews with coworkers, but also the article's conceptual innovation. Although they address the concept of "affective touch," which seems to be a popular if sometimes vague conjunction in social robotics, Barker and Jewitt find that this applies predominantly to a single user's interaction through direct touch with a robot. Instead, their industrial setting is one where direct touch is extremely dangerous, where other sensory demands (heat, noise, movement) were prominent, and where rhythms of machine movement and human working became established over time. As such, they find the social and industrial environment as more unevenly distributed, and they express their findings through an alternative formulation that acknowledges these uneven distributions, the "tangled passages," and touches on the more philosophical formulation of affect described earlier in this special issue introduction. Their framework for examining touch through bodies, technologies, and environments is one derived through Jewitt's IN-TOUCH project, which has looked at other haptic technologies previously.

The article by Paul Bucci, David Marino, and Ivan Beschastnikh entitled "Affective Robots Need Therapy" examines the theoretical foundations in HRI for approaching emotions. The authors point out that the modern statistical approach is unfit for the study designs of in situ emotions in terms of categorical, methodological, and instrumental design. In response, the authors advocate the application of the constructivist theory of emotions, for constructivism honors that the human experience of reality is a subjective experience that is influenced by culture and prior experience as well as physical reality. The associated challenges in applying this theory rest in the processing of the ambiguous subjective data. For this, the authors propose to look for ontological, epistemic, and methodological guidance from psychotherapies including cognitive-behavioral therapy, somatic therapies, narrative therapies, and trauma-informed approaches.

The gap between the physical robot morphology and the user expectation of them is the foundation of the ambitious article "Design Metaphors for Understanding User Expectations of Socially Interactive Robot Embodiments" by Nathaniel Dennler, Changxiao Ruan, Jessica Hadiwijoyo, Brenna Chen, Stefanos Nikolaidis, and Maja Matarić. The article starts by establishing what they mean by "design metaphors" for the physical appearance of robots, including kiosks, dogs, and humans, going from "abstract" to "literal" in terms of their representation. Because of their physical instantiation in the spaces of human interaction, they argue, the presence of robots prompts *social* expectations as well as *functional* expectations by users. The authors ask what such expectations entail for the design of robots, and they offer an open source dataset as a resource for other designers to consider these issues, what they call the *Metaphors for Understanding Functional and Social Anticipated Affordances* (MUFaSAA) dataset. Along with this dataset, they describe their three crowd-sourced studies that assess the effect of robot design on user expectations of the capabilities of robots. This rather comprehensive dataset involved manually coding 165 instances of robots, incidentally acknowledging certain design trends around height and color, and then a series of crowd-sourced studies through MTurk of qualitative perceptions by users of the robots' physical design, the social expectations, and the functional expectations. The result of this impressive dataset will be of value to interaction designers to understand user expectations more accurately and offers granular recommendations based on the anticipated placement of a social robot.

Jacqueline Urakami and Katie Seaborn's "Nonverbal Cues in Human-Robot Interaction: A Communication Studies Perspective" returns to the value of nonverbal communication for HRI design. Focusing on nonhuman interactions with human users as a way to convey "liveness" or, in Japanese, *kokoro*, they underline the significance of nonverbal gestures, facial expressions, eye movements, and other nonverbal "codes." Urakami and Seaborn have mined the HRI literature to produce a systematic listing of several nonverbal codes, citing extensive studies in each case, which may be a useful resource for roboticists unfamiliar with the literature. Along with the more usual inclusions such as haptics and proxemics, the article includes sections on other design factors that may play into a user's interpretation of nonverbal codes, such as body type, the use of clothing, and smell. Furthermore, gestures are broken down into categories that are interpreted on their own, or which accompany speech or other nonverbal behaviors.

Like the article by Dennler et al. described earlier, Ela Liberman-Pincu, Yisrael Parmet, and Tal Oron-Gilad take a systematic scalpel to the visual appearance of the robotic body and present a taxonomy of design features, including a robot's color, silhouette, dimensions, and materials, and more in their "Judging a Socially Assistive Robot (SAR) by Its Cover; The Effect of Body Structure, Outline, and Color on Users' Perception." Based on their taxonomy, the authors synthetically generated 30 abstract robot designs, which they realized as 3D models, presented in a simulated environment for user evaluation. The authors' visual features were grouped into three **Visual Qualities (VQs)**: structure, color, and outline, and then correlated with participants' evaluation of the robot's qualities. Liberman-Pincu et al. found relations between each of the VQs and characteristics of interest, such as that A-shaped and hourglass-shaped robots are perceived as friendlier than, for example, V-shaped robots. Similar relationships were revealed between VQs and a robot's gender perception. In a follow-up study, the authors allowed users to specify their own preferred VQs for a socially assistive robot in their own home. Cross-referencing the two studies, the article concludes that people preferred VQs associated with friendliness rather than elegance or innovation.

In "Embodied Expressive Gestures in Telerobots: A Tale of Two Users," William Benson and colleagues focus on a single part of a robot's body and take a look at the social role of a robot arm in a telepresence scenario. Their hypothesis is that interacting with social arm gestures, such as handshakes and fist bumps, can enhance telerobotic interactions and support the social connection between the robot's operator and the human interacting physically with the robot. To investigate this question, the authors built a lightweight social manipulator arm with five degrees of freedom, supported by operator tracking software to translate their gestures to the robot. Operators could express arm and hand gestures such as "high five," "thumbs up," and "stop," to name a few. Most of the gestures had a high recognition rate, increased the length of interaction, and improved interacting (local) users' affect and enjoyment. Somewhat surprisingly, the users who interacted with the robot also felt that the robot with the arm was less anthropomorphic and animated than a telepresence robot without an arm. These findings could indicate design tensions that come with adding degrees of freedom to a telepresence platform.

In her article "Applying 'Designerly Framing' to Understand Assisted Feeding as Social Aesthetic Bodily Experiences," Sara Ljungblad synthesizes knowledge from design into HRI design of an assisted meal experience. The article introduces a technique called *designerly reframing*, which, instead of focusing on usability, foregrounds the social and aesthetic perspectives of a holistic experience. This technique is about "the process of addressing the right problem, making sure that the overall question framing the design process is sound in order to avoid developing unsuccessful solutions." The article provides a case study of assisted feeding of five people with impairments in their arms or hands, among whom four have the experience of using a robotic eating aid. Designerly framing was applied to unpack "the meal as a cultural, aesthetic, and bodily sensation." To bridge the two parallel worlds of design and HRI, the author contextualized the technique of designerly framing in relation to various other experience-oriented practices, including soma design, user-centered design, and embodied design.

Yuhan Hu and Guy Hoffman's article also deals with design and specifically argues for a broadening of the robot designer's perspective when it comes to a robot's skin. In "What Can a Robot's 'Skin' Be? Designing Texture-Changing Skin for Human-Robot Social Interaction," the authors argue that whereas biological skin fulfills several functions, such as protection, sensing, expression, and regulation, robot skins usually mostly serve as barriers with some limited sensory function. Hu and Hoffman present a taxonomy along which robot designers can understand the variety of roles a robot's skin can fulfill and then provide a deeper dive into the expressive capability of robot skins. In this vein, the authors suggest a biomimetic approach of dynamic skin textures as an expressive modality and present fluidic "texture units" and "texture modules," a technology that could enable this goal. Hu and Hoffman illustrate this technology with six built prototypes, such as goosebumps, furrows, scales, and tentacles.

The final article, "From Robotics to Prosthetics: What Design and Engineering Can Do Better Together" by Maria Fossati, Giorgio Grioli, Manuel Catalano, and Antonio Bicchi, revolves around a user-centered case study of the design of a prosthetic hand. The "user," in this case, is the first author of the article. This work is unusual in several respects. It integrates the design and engineering into a user-centered approach where the user, Maria, is part of the team conducting the iterative modification of an off-the-shelf robot hand solution, to fit and then become further integrated into her lower arm and, in fact, her body as a whole. This becomes not just a prosthesis or artificial hand as appendage, then, but what the authors term a *user-hand system*, with implications for psychological factors in terms of behavior and appearance, and of course disability and rehabilitation engineering. Experimenting with soft materials to help with grip, making it look less uncanny (what they call the *evil cyborg* trope), and putting the hand through a series of experimental scenarios for gripping, grasping, and gesturing, the article documents a promising case study in integrating users tightly into the design process. The article also acknowledges the importance of appearance of the user to the outside world, not just the form of the hand but also of its behaviors. A virtue of the approach the article takes is how, while the first author is simultaneously the experimental subject, the design process might be replicable with other groups of users, such as amputees or those with motor disabilities.

The works presented in this issue have taken up the prompt to consider the robot body in design in rather different ways. As editors of this special issue, we are proud of the contributions, some of which came from established roboticists, and some, as we hoped, coming from the areas of design and social science. However, there is need for caution. Some of the terminology and concepts from design, social science, and psychology that so invigorate this special issue can be problematic if not carefully "translated." In other words, the work of translation from one disciplinary field to another was sometimes difficult and required careful contextualization. This was achieved by reaching out to reviewers from beyond the usual realm of robotics expertise and coordinating their responses as special issue editors. The special issue editors themselves reflected this multidisciplinary effort, consisting of a roboticist (Hoffman), a designer (Yan Zheng), and a social scientist (Paterson). As we assigned the works to reviewers, we therefore tried to invite expertise from different perspectives and disciplinary backgrounds. This turned out to be a much larger and more complex effort than initially envisaged. Along with providing the expected scrutiny on the methodologies and data produced in various scientific studies, some reviewers were also quick to seek clarification on the terms introduced, posed constructive questions, and provided suggestions for better contextualization of these concepts. Behind the scenes, the reviewing process has therefore been a crucial cross-disciplinary dialogue in the production of this special issue, resulting in greater clarity within our finalized works and consequently for the issue as a whole. Although reviewers are always crucial to the evaluation of manuscripts considered for publication, we extend special thanks to the reviewers involved in this special issue. It is our hope that the final result, the works that follow, will be beneficial for the ongoing project of "translation", and the contextualization of terminology and concepts, that will enrich the already impressively multidisciplinary and thriving field of HRI.

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