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Embodiment in Socially Interactive Robots

Eric Deng
University of Southern California
denge@usc.edu

Bilge Mutlu
University of Wisconsin–Madison
bilge@cs.wisc.edu

Maja J Matarić
University of Southern California
mataric@usc.edu

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Contents

Embodiment in Socially Interactive Robots

Eric Deng[1], Bilge Mutlu[2] and Maja J. Matarić[3]

[1] *University of Southern California; denge@usc.edu*
[2] *University of Wisconsin–Madison; bilge@cs.wisc.edu*
[3] *University of Southern California; mataric@usc.edu*

ABSTRACT

Physical embodiment is a required component for robots that are structurally coupled with their real-world environments. However, most socially interactive robots do not need to physically interact with their environments in order to perform their tasks. When and why should embodied robots be used instead of simpler and cheaper virtual agents?

This paper reviews the existing work that explores the role of physical embodiment in socially interactive robots. This class consists of robots that are not only capable of engaging in social interaction with humans, but are using primarily their social capabilities to perform their desired functions. Socially interactive robots provide entertainment, information, and/or assistance; this last category is typically encompassed by socially assistive robotics. In all cases, such robots can achieve their primary functions without performing functional physical work.

To comprehensively evaluate the existing body of work on embodiment, we first review work from established related fields including psychology, philosophy, and sociology. We then systematically review 65 studies evaluating aspects of

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embodiment published from 2003 to 2017 in major peer-reviewed robotics publication venues. We examine relevant aspects of the selected studies, focusing on the embodiments compared, tasks evaluated, social roles of robots, and measurements. We introduce three taxonomies for the types of *robot embodiment*, *robot social roles*, and *human-robot tasks*. These taxonomies are used to deconstruct the design and interaction spaces of socially interactive robots and facilitate analysis and discussion of the reviewed studies. We use this newly-defined methodology to critically discuss existing works, revealing topics within embodiment research for social interaction, assistive robotics, and service robotics, in which more extensive exploration would greatly improve the current understanding of the impact of embodiment on human perception and evaluation of human-robot interactions.

The introduced taxonomy for embodiment design is used as a starting point for outlining our characterization of the design space of robot embodiments. The presented characterization can be used to discuss how the physical embodiment of socially interactive robots relates to social capabilities and affordances. By introducing a general model of the design space, existing research findings can better advise robot designers and we discuss how these findings can inform researchers through design decisions in the development of future socially interactive robots.

Keywords: Embodiment, Human-Robot Interaction, Social Robotics, Product Design, Human-Computer Interaction, Service Robots, Reporting Guidelines, Methodology

1

Introduction

As technology development and sophistication continue to progress at an ever-growing rate, automated systems are quickly becoming integrated into everyday life. These systems have assisted humans in tasks ranging from scheduling [31], ordering food deliveries [274], entertaining guests [36], enhancing assembly line work [275], and coaching physical and mental health activities [159].

A growing subset of these technologies are artificial agents, whether they be on-screen, in virtual reality (VR), or physically embodied. We are witnessing parallel and synergistic growth of the core technologies of artificial intelligence, computing, and manufacturing, all facilitating the development of interactive artificial agents. Researchers and engineers working in human-robot interaction (HRI) and socially interactive robotics are designing, building, testing, and deploying robots that interact with humans and perform a wide range of tasks [98] as partners in a growing number of domains including manufacturing [12], healthcare [130, 256, 294, 304, 222], education [262, 103, 54, 283, 142, 100], and entertainment[146, 270, 239, 150].

As these robots are interacting with users through primarily non-physical means, it is critical for them to be able to engage in effective social interactions. Embodiment provides the opportunity to leverage more channels of communication, including proxemics [282, 197, 199], oculesics [218, 4, 4], and gestures [35, 273] to enhance communication and the perception of being more trustworthy [250], helpful [250], and engaging[146] than disembodied agents.

Although embodiment is a defining feature of robotics, the study of embodiment and embodied behavior predates robotics and extends well beyond it; it spans many fields of study, including neuroscience [76], philosophy [116], and social sciences [101, 143].

How critical is the physical embodiment of a robot in human-machine interaction? Embodiment is clearly a necessity for robots that physically interact with and manipulate objects, but most socially interactive robots do not physically interact with the environment to achieve their goals [163, 85]. As a result, in such contexts, the benefits of physical embodiment over less expensive and complex virtual presence is less obvious [122]. This work explores the embodiment hypothesis in socially interactive robotics: **"the hypothesis that physical embodiment has a measurable effect on performance and perception of social interactions"** [296].

Research in human communication and psychology has explored both physical and virtual embodied cues as tools for improving social interaction, including gaze behavior [14], head movements [13], and the persona effect [209]: the affective impact of artificial agents in social interaction. Kantian philosophy introduced the concepts of the mind-body and subject-object problems in relation to the embodied view in the mid-1700's [101, 143], leading to the development of the "modern" embodiment hypothesis outlined by Ortega and Gasset [230], Heidegger [115], and Merleau-Ponty et al. [203] and [83, 24]. Embodied cognition spans these fields, bringing together the work of Brooks [42] and Moravec [205] in robotics and sensing, the modern-day philosophy of Clark [56, 55] and Hendriks-Jansen [116], and research in neuroscience and biology from Edelman [76], Longo et al. [179], Damasio [63], and Rosch et al. [257]. In human-computer interaction, non-physical interactions with artificial agents in social interactions have been studied [51], specifically exploring the design of such systems for social abilities and quality of interactions they can produce [249, 155]. In robotics, specific dimensions of social interaction have been explored, as has the influence of the design of physical embodiment on interaction [297], engagement [146, 282, 299], trust [25, 27], and the perception of an agent [45, 139, 146, 282, 296, 299].

Previous work in robotics suggests physical embodiment can increase engagement and enjoyment in social interactions with humans [15, 146, 296, 297]. This paper presents a thorough review of existing work and analyzes existing results and approaches to embodiment to determine the current state of the embodiment hypothesis. As research continues to validate the importance of embodiment in *socially interactive robots*, the implications on robot design will become more apparent, because both the theoretical and practical importance of physical embodiment for human-robot interactions translates into real-world applications through appropriate embodiment design. In this meta-review, we study various robotic platforms, most of which were designed for research uses, and then adapted to task-specific applications within research studies. We explore these embodiments and approaches [218] to collecting data toward quantifying the subjective qualities of the robot's physical embodiment. We then describe our characterization of *the design space for socially interactive robots* toward informing both future designers and researchers.

The rest of this paper is organized as follows. We first discuss the definition of embodiment in relevant fields of study, review past work in related fields, and introduce terminology for the rest of the paper. We then introduce a taxonomy of robot embodiments that provides the contexts for human-robot interactions in the surveyed studies. We then discuss the current state of the embodiment hypothesis in socially interactive robots based on the existing body of work, provide suggestions of areas that need further exploration, and recommend approaches that aid in the design of more structured studies. Finally, we introduce a characterization of the design space of socially interactive robots, discuss how different components of a robot's design relate to aspects of social interaction, and present an approach to leveraging existing research to design or select robot embodiments for future work.

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