

# Social Robotics: Enhancing Human-Computer Interaction

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## ABSTRACT

Social robotics is a rapidly evolving interdisciplinary field that merges robotics, artificial intelligence, cognitive science, and human-computer interaction (HCI) to develop robots capable of engaging in social behaviors with humans. These machines are not only functional agents but also social actors embedded in human environments. Inspired by biological organisms and social behavior in nature, social robots are designed with anthropomorphic features, affective communication capabilities, and adaptive learning systems to enhance engagement, companionship, and cooperation. From healthcare and education to entertainment and eldercare, social robots are redefining how humans interact with machines. This paper explores the historical development, theoretical foundations, design principles, communication frameworks, and ethical considerations of social robotics. By examining the diverse applications and challenges of human-robot interaction, particularly in emotional cognition and social modeling, the study highlights the potential of social robots to transform digital ecosystems and human society. It concludes by addressing future pathways and open issues in creating more intelligent, ethical, and emotionally responsive robotic companions.

**Keywords:** Social Robotics, Human-Robot Interaction (HRI), Human-Computer Interaction (HCI), Affective Computing, Anthropomorphic Robots, Ethical AI, Robotic Companions, Emotion Recognition, Robot Design Principles.

## INTRODUCTION

Societies of animals rely on social bonds formed through interactions and behavioral patterns, initiated by various signals in a series of phases. Even simple organisms can perform diverse tasks with sufficient time for planning. This principle applies to both biological and robotic entities. However, delays can lead to negative outcomes or the emergence of novel behaviors, such as hunting or escape tactics in birds and insects. By emulating these natural movements, innovative robotic workstations may be developed. A significant shift in the global social robot development contest is the inclusion of robots imitating animals, ranging from simple models like Aibo to complex instances involving memory and learning. A notable robot, iCub, showcases a high level of anthropomorphism and social complexity, with motor systems compared to bio-inspired cyber insects. These developments aim to foster autonomous learning, enabling robots to adapt to complex social dynamics throughout their existence. Animal robotics is an emerging discipline focused on creating biologically inspired robots to study body-brain-behavior relationships in various species, testing behavioral hypotheses, applying findings biomedically, and enhancing robotic designs. This research views animal robotics as part of social robotics, encompassing all robotic entities that engage through diverse interactive modes. To alleviate the complexity of developing social robots, some demonstrator models are designed to showcase and assess emerging behaviors and interactions across different societal types [1, 2].

### Historical Context of Robotics

The development of machines generating, exhibiting, or ensuring some characteristics of human behavior is the core of robotics. There are several branches of robotics: industrial (robots for manufacturing),

service (transportation, repair, cleaning), entertainment (toys, virtual actors), educational (teaching, training), medical or rehabilitation (surgery, physiotherapy). All kinds of robots are additionally designed or programmed for interaction with humans. Human-robot interaction (HRI) covers all issues of such interactions – perceptual mechanisms of robot recognition of human movements, gestures and speech; communicative mechanisms of robot control of human attention; cognitive understanding of human governmental contexts; motor interaction: imitation, participation and generation of human-like movements; procedural learning of movements and the best strategy selection. HRI is common not only for robotic devices but also for robotic simulations in a 3D virtual space. Because of different motivations and offered capabilities and roles, innovative participative HRI is targeted at the cooperation of multiple robots and/or humans in a common problem domain. Unfortunately, they are still not popular. Robot companions gain their popularity mainly because of the emotional and social features of HRI. All such robots have several human-like attributes such as anthropomorphic shape and movement, vision and speech perception, motion imitation, and interpersonal distance control. Some of them can also produce simple emotions or start learning about human preferences. These features allow robots to be accepted as partners in emotional or social communications. This kind of HRI raised the question of rethinking the philosophy of interaction with intelligent technology and its artistic design. The main initial and primary interpretation of HRI was its cognitive capabilities (perception, representation, and understanding of human utterances and actions). Then affective or emotional aspects (understanding and mapping of emotions, elicitation of human affective reactions) were added. However, such classification of HRI capabilities seems to be insufficient for robot companions because the human side of communication is more complex and richer than such simple cognitive and emotional schemes. Understanding of the common communicative context, enabling design and conduct of several communicative strands according to humans' requests and companion's capabilities, inter-discursive focus management, and temporal organization of communications are critical issues widely studied for HCI, but still not considered for HRI [3, 4].

#### **Theoretical Foundations of Human-Computer Interaction**

In today's society, everyone is reliant on computers to handle their work-related files, conduct research, and streamline everyday chores from groceries and travel to transactions and entertainment. The world around you is utterly inundated with technology. Thanks to the vast computer networks spanning the planet, mass communication is instantaneous, and on-demand information is available literally at your fingertips. But with the advent of these technological marvels, computers have advanced so far aside from the aforementioned tasks, with immeasurable reservoirs of personal files, essential Bluetooth devices, complex file systems, and digital registers required for all transactions, which can be quite overwhelming. This fear of technology is called Technophobia. Consequently, the fear or phobia of computers or software application systems, which could stem from a fear of the consequences of misunderstanding those systems and the frustration of understanding those systems, is termed as Techno-Phobia. A large amount of human-computer interaction research has sought to model and understand typical interaction patterns, leading to heuristics and guidelines for design. Such research invariably assumes the computer is a non-human, mindless entity with a fixed repertoire of actions afforded to it by the designer. Human behavior is expected to adapt to the limitations of the computer, which is often implemented in the same medium as the designed computer interface. Social, partially-observable, adaptive systems such as climate control or focus cameras react to in situ sensory cues to influence the behaviour of the people who interact with them in ways that cannot be encoded with conventional interfaces. In such cases, the medium of interaction is sometimes separate from the medium of design, for instance, a complex building management system [5, 6].

#### **Key Components of Social Robots**

Social robots are predefined as machines with an autonomous nature designed to co-exist and enhance social development on their own. They are sociable articulations instrumented with generally distributed internal states (affect, motivation, desire, etc.) that lead them to engage in flows of actions affecting both the environment and their peers. The more social ways they interact, the more they become novel tools assisting humans in various tasks: to combat social isolation of elderly people, inform users on health issues in hospitals, persuade children engaged in healthy behaviors in schools, and so on. In this advent, HRI researchers proposed key features that became the core of social robots. Due to the complex nature of social interaction, one of the elementary functions to be provided in initial implementations is mechanically proximate and ambient behaviors able to compensate for an insufficient reactivity to the agent's behavior. These behaviors mislead the interaction toward a specific state desirable for further conversational ordinate topology modifications. Outcomes of computations in these procedures lead social robots to behaviors that are socially oriented. Meanwhile, higher levels of interaction must affect return

flows as well, to reroute the interaction toward states that were not previously provided by the robots due to either interaction's or social actors' fault. Likewise, in HCI, ontological representational interoperability over input and monitoring channels must be defined. These representations may refine computations in processes needing cross-channel cooperation and may control all agents' states. Achieving human-level social interaction is the Holy Grail of HRI, although a good approximation to such a vast area of investigation will bolster lots of potential commercial applications. Meanwhile, robots are required to specify and parameterize key components of social interaction that dictate lower-level behaviors. Features or social skills become necessary to be considered in development to constrain the design space. Social robots are a novel environment with new actors exhibiting both sociability and computability that brings along a new set of phenomena affecting social interaction [7, 8].

#### **Types of Social Robots**

Anthropomorphic, these robots bear a physical resemblance to humans, or part of a human. They can have fixed or movable heads, arms, legs, with a jointed structure, thick or thin, and a tall or short shape. In the 1980s, a humanoid robot named WABOT-1 was developed in Japan. It has functions of walking, turning, and even carrying a 10kg burden. Additionally, a robot named ASIMO is another example of managing multi-sensor information for intelligent motion generation. The developmental plan of these robots also strives to develop human-like visual and recognition capabilities. Humanoids. Usually, humanoids may include two types of robots: anthropomorphic and anthropoid robots, which are human-like physically. Many robots are built without a human-like face, but they can still identify with humans effectively. These robotic faces can also carry facial abilities, such as eye blinking and facial expression. Further, the development of robot hands has been improved to ensure dexterous motion and object manipulation. More well-known examples of social robots are humanoid robots that are designed to imitate a head and face. On the other hand, humanoid robots account for a smaller proportion in the social robots market. Thus, the robot faces are designed to form many different shapes, from convex to concave, non-anthropomorphic to non-differentiated. Robot faces create a floatable style between the humanoid structure and the abstract style. They can maintain user identity recognition and expression understanding even if the style is ruled out. Many types of social robots do not refer to anthropomorphic and non-anthropomorphic human structures, but can interact with people. These robots might be used at a medium distance, as meek workers in an administrative job, or for a lively and natural interaction. Nevertheless, in many cases of laboratory design or layout, a self-naturally moving robot, such as a manta ray-like robot in seawater, can be personified by nonhuman-embodied features. Moreover, other well-known social robots also fall on the abstract robot dimension. Most convenient webpages or any computer devices with an animated presenter, without any fixed physical embodiment, can also be called social robots [9, 10].

#### **Design Principles for Social Robots**

The following principles emerged during the design of the MARIO robots and are meant to inspire designers and researchers engaged in the design of social robots. They are classified into three distinct classes: principles that aim at directly affecting the robot's behaviours, actions, and personality; principles that enhance the robot's intelligence; and principles that facilitate the design and implementation of the robotic solution. Each principle is presented offering its ethical rationale, followed by indicators on how it can be implemented, and is iterated afterwards proposing design and implementation solutions previously adopted regarding it. Social robotics poses tough challenges to software designers who are required to take care of difficult architectural drivers like acceptability, trust of robots, as well as to guarantee that robots match the children's needs and establish a personalised interaction with them. Designing and implementing social robotic software architectures is a time-intensive activity requiring multi-disciplinary expertise: this makes it difficult to rapidly develop, customise, and personalise robotic solutions. In addition, many solutions and choices adopted in a particular project are hardly transferable and reusable in different settings. These challenges may be mitigated at design time by choosing certain architectural styles, implementing specific architectural patterns, and adopting particular technologies. The principles proposed suggest the adoption of particular design and implementation choices regarding the architecture of social robotic solutions [11, 12].

#### **Communication in Social Robotics**

Communication will be a key topic in a social robotics workshop. Following the previous review of existing literature, in this section, a few possible areas of communication relevant to social robotics are flagged. Some literature on social robots is reviewed in detail. Last, some concluding comments are made. There are many areas of communication relevant to social robotics. Most existing research on social robots focuses on human-robot interaction, on which there is an overview in the form of a meta-analysis;

on user experience studies; and on a relatively small literature that focuses on the implications of social robotics. Many designs of social robots in use in society are not as good as they could be. A better understanding of design choices in social robotics is needed. A social robot is just one component of a larger digital ecosystem. Communication views may help to understand how social robots are used with other types of communicative agents, such as smart speakers and avatars on websites. Some design choices from existing social robots are analyzed to illustrate how communication views may facilitate better response systems. The kind of robots that are used directly for human-robot interaction, such as speech and humanoid robots. A robot seems to be a good basis for a social robot because many of the existing robots have the properties of good designs, but they may miss some. For example, a high-tech pace robot failed brilliantly in a research study because it was designed to present science to children instead of them presenting it to them, and then it lost its appeal. Examples of communication for interaction and responses, such as simplistic robotic talk and conversations between smart speakers, are also illustrated. Those designs have communicative edge cases [13, 14].

#### **Ethical Considerations in Social Robotics**

Robots, as computers, have the potential to make the world better. Exploring this potential and making better robots is a rich technical and scientific challenge. However, there is a growing awareness that technical quality is not enough. Technical systems need to be trustworthy and accepted, so they stay in their intended solution space. This is evident in the case of social robots. Machines are increasingly engaged in social behaviors and become part of social systems where their influence on ethical and moral conduct is profound. Existing social norms, interpersonal relationships, and ethical choices are influenced by the interactions. However, there is a risk of violating Convention- and Norm-based notions of acceptable behavior, which can lead to adverse consequences. Therefore, an early understanding of the ethical implications of social robotics is needed. With the emergence of social robotics, machines capable of deliberately engaging in social, emotional, and affective interactions are beginning to invade personal social spaces. School children share their thoughts and actions with them; elderly people rely on their support for care and companionship; humans take them for friends for love or sexual engagement. Social robotics refers to the deployment of personal robots in social contexts that involve interaction and communication with humans. In these settings, humans perceive the robot as a social agent, and the interaction is expected to be social rather than merely task-oriented. These new uses of robots offer great opportunities for enhancing quality of life and welfare, especially in the face of the social challenges posed by aging populations, dwindling resources, and rising inequalities. However, the social and ethical issues raised by these technologies are great and poorly understood. Robots resurfaced as a promising way to develop technology following the emergence of the automaton, machines capable of mimicking human behaviors. The extent of robotics then was the replication of motions alone. Robots were immobile while data and computer technology evolved. The introduction of artificial intelligence in the robotics domain transformed the notion of robotics, and robots became mobile and cognitive machines capable of sensing their environments and making decisions on their own. Social robotics formed a bridge between the developments in the fields of robots and machines [15, 16].

#### **Applications of Social Robotics**

Social robotics is an emerging discipline of robotics that deals with the design of robots to interact with humans socially. While industrial robots revolutionized large-scale industrial mass production, social robots are expected to assist humans by taking over different tasks domestically, in elder homes, during leisure time, or at workplaces. The increasing demand is reflected by the spread of different kinds of robotic devices from toys to vacuum cleaners. However, not all robotic devices can be categorized as social robots, as they cannot socially interact with humans. Here, social robots are defined as machines that can form social relationships with humans via social interaction. In this interaction, the robot could take the role of a social partner, whose behavior could be ascribed social meaning and could influence the behavior of humans. According to this, the current mainstream of social robotics focuses heavily on the production of human-like social creatures. This focus is rooted in established psychological theories claiming that humans have a bias for social partners who are similar to themselves. Thus, those robots whose embodiment and behavior possess human-like features are expected to yield relevant and meaningful conversational contexts for the general population. Nevertheless, social robotics is an interdisciplinary field dealing with several scientific challenges. Physical and software design of social robotic systems is a primary focus of this research area. Within this, the most regarded subdomains are human-robot interaction, a task-level interaction dealing with human-robot collaboration, and human-robot communication, where the goal of interaction is generally communication and conversation. It is expected that in the future, social intervention robots – robots able to socialize, build social relationships,

and co-operate with humans in a direct interaction using natural communicative and social behavior – will emerge [17, 18].

### **Challenges in Human-Robot Interaction**

Social robotics for social HCI centers on the social cognition of humanoid robots. One important aspect of social cognition is the perception of emotion. Emotion is one of the key factors in determining human social behaviors. Affective computing deals with how machines and devices can perceive, understand, and respond to emotion in a human-centered manner. Many concepts and systems of affective and empathic robots for social HCI have been developed and tested. Nonetheless, design guidelines and cognitive models of emotion in humanoid robots for social HCI are still minimal. There is a vast area of human emotion and a plethora of theories regarding mechanisms and other issues. It remains a challenge to find which concepts are suitable for defining robot emotion, perception, and expression in social HCI. The focus is on chatbot-type social HCI and how to apply major theories and models of emotion to chatbot humanoid robots. Philosophical psychologies and cognitive modeling of basic emotions, mood, and social emotions are illustrated, choosing theories suitable and possible for robots. Uploading active and selective attentional mechanisms with arousal and valence, dynamically modified robot states, and social behaviors are discussed. Theories of development and learning are also presented. How to develop basic perception and behavioral capacities of affective mobile robots must also be one of the challenges in emotional cognition of social robots, embedding self-regulatory mechanisms and behavior skills [19, 20].

### **Future Trends in Social Robotics**

To make communication possible between a robot and a human, communication technology must comply with a set of conditions that derive from the status of the robot. This requirement is regarded as independent of the type of interaction, the social, informational, or other dimensions of the interaction, as well as the format of the interaction might have. The human adds a machine if the relevant and necessary criteria imposed by its status and by scientific knowledge are satisfied. The interests of the human guide whether a technical system is developed that can be regarded as and treated as a communication partner. If so, those interests motivate the building of an interactive social robot. Several topics are relevant for the physical and social design of human-robot interaction. These topics have diverse character before they are turned into concrete questions within a research agenda, but they can be organized and conceptualized as the three dimensions of physical and social design: technical conditions on the data layer of an interaction system and individual socially interactive behavior, interpersonal and interactively generated conditions on the social design of an archetype or type of social robot, and conditions on the social order around and development of a species of social robots. This view identifies a logical and practical hierarchy of design types. Specifically, concerning autonomous social robots, it is claimed that psychology has only a limited role to play in the development of interactive communicative robots. It is argued that to make a new generation of rudimentary social robots possible, there is a need to derive design principles from the general theory of mind that serves as a foundation of both social play and social contagion. These principles can be made concrete and could be integrated into social robotics engineers' technical knowledge bases as design theory or knowledge that controls construction and specification procedures of interactive social robots [21, 22].

### **Case Studies of Successful Social Robots**

The evolution of interaction with the Robo-Barista over six weeks focused on four key acceptance factors: perceived usefulness, likeability, perceived trustworthiness, and perceived adaptability. Data were collected through a mixed-method approach, including self-reports via questionnaires, direct observations at six time points, and robot logs with metadata. Users generally had a positive view of the Robo-Barista, leading to frequent use. Interaction behaviors changed over time, with participants adapting to the robot; however, perceived usefulness and likeability both slightly declined, while trustworthiness increased consistently, and adaptability remained stable. These findings underscore the significance of monitoring changes in attitudes for designing intuitive social robots. A preliminary study compared a café robot and a social humanoid robot to understand how different features influence usage behavior across venues. Factors such as service types, design, interaction styles, and data processing affected user engagement. Participants rated perceived ease of use, trust, and enjoyment for each robot using a six-point Likert scale, with further analysis via common model fit indices. A conceptual framework was proposed to clarify how robot features influence usage behavior in diverse settings. Results emphasized the intricate relationship among robot features, user knowledge, beliefs, and behaviors. Service robots are increasingly integrated into daily life, designed for assistance, entertainment, and companionship in various environments, from schools to homes. Despite limited understanding of how various robot features impact user behavior, some service robots have demonstrated success in their niches [23, 24].

### User Experience Research in Social Robotics

Communicating with social robots and developing user experience (UX) necessitates longitudinal studies. This area explores the signaling in human-human and human-robot interactions. A signal connects a sender (source, S1) with a receiver (interpretant, I), consisting of the signal itself, what it references (object, O), and how the interpreter perceives it. When one individual models the knowledge of another, a representation of O is built in I based on S's knowledge. The signal links me to S2 through knowledge representation using sign vehicles like body language, facial expressions, and gestures. Nonverbal communication encompasses interactions beyond words, including visuals, symbols, proxemics, haptics, voice modulation, and gestures. In human-robot interaction (HRI), humanoid robots can emulate human-like communication to exchange social signals effectively. Humans utilize verbal and nonverbal actions to express sociocultural and technological traits, and similarly, social robots require coordination of various communication modalities for human-like behaviors. The capabilities of social robots are under examination in contexts like AI2, focusing on information flow and mutual knowledge formation. There is growing attention on social robots in intelligent smart homes, discussed from human, design, and impact perspectives. Here, robots act as user agents for UIs that facilitate user interaction with digital services. However, a human-centered design must consider the societal impacts of this technology, promoting a sustainable digitized society [25, 26].

### Cultural Perspectives on Social Robots

With the advent of artificial intelligence, social robotics started entertaining a particular relationship with anthropomorphism. In social robotics, anthropomorphism is neither seen as a cognitive error nor, regarding social robots meant for childcare/senescence support, as a sign of immaturity. On the contrary, in the computational paradigm of social robotics, anthropomorphism is considered a common human tendency that is hypothesized to have evolved because it filtered the kind of life-form to which cooperation favored human beings over their competitors. Among those, humans fared better with entities willing to engage in reciprocal exchange of cooperation to mutual benefits: since those entities tended to have a human-like phenotype, the emergence of the naïve belief that other entities were similar to themselves favored the emergence of such a better filter. As a result, competitive evolution should have favored species and individuals (modern humans) who would more easily engage in anthropomorphic projections towards entities (peers, other humans, social robots) endowed with signs of similar positive interaction history. Such cognitive currents, apart from potentially misleading entrustment behavior towards self-serving agents, are also seen as prone to eliciting social awareness vis-a-vis robots (companionship, support, care), which is believed to lead to safer and more compliant social robots. Applied anthropomorphism drives the mainstream technology development for social robots, and social roboticists concur with the premises and the conclusions of the anthropomorphism revival debate. Yet, what applied anthropomorphism cannot do is to realize by construction the kind of sociality proper to living species [27, 28].

### Impact of Social Robots on Society

Researchers from various disciplines, while conflicting in some respects, agree on the important impact of social robots on society. Relevant questions are about cultures, age groups, and conditions in which the impact is being studied, and whether uncontrolled robots will harm societies, social structures, individual perceptions, or ethical norms. Socially interactive robots are being perceived differently by the elderly and the very young. A prevailing concern in recent years has been the impact of social media. At the same time, there is a hope that robots can bring a beneficial impact. It is very important for this research area to admit that it will study not only the beneficial influence, but also benign or harmless robots. A very important question about socially embedded robot design is how and in what sense robots would be to embed humanity's cultural heritage. What should robots be, and what should not be simulacra? What kind of bytes can carry sociality and culture? It is still not known whether understanding is necessary for a robot to bear the salient aspects of cultural scripts and narrative persuasion (rather than autistic, sensory-stimulating robots). Tumultuous technological advancement opens many new queries simultaneously for robots. Usage of robots in settings not yet foreseen at their design phase raises questions that designers, ethicists, or visionaries who heralded their arrival could not envision. Some weighty questions are how robots should be and in what cultural and historical context they would function [29, 30].

### CONCLUSION

Social robotics stands at the forefront of technological innovation, redefining how humans and machines coexist and communicate. From mimicking biological behavior to advancing emotionally intelligent interactions, these robotic systems aim to bridge the gap between computational efficiency and human-

centered design. As robots become more sociable, ethical considerations surrounding trust, autonomy, and societal impact become increasingly relevant. To fully harness the benefits of social robotics, future research must emphasize cross-disciplinary integration, human-centered design, and ethical development frameworks. Addressing these dimensions will not only improve robot usability and acceptance but will also enable the creation of machines that can truly enrich human life emotionally, cognitively, and socially.

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