Understanding Social Robots

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Abstract

Research on social robots is mainly comprised of research into algorithmic problems in order to expand a robot´s capabilities to improve communication with human beings. Also, a large body of research concentrates on the appearance, i.e. aesthetic form of social robots. However, only little reference to their definition is made. In this paper we argue that form, function, and context have to be taken systematically into account in order to develop a model to help us understand social robots. Therefore, we address the questions: What is a social robot, what are the interdisciplinary research aspects of social robotics, and how are these different aspects interlinked? In order to present a comprehensive and concise overview of the various aspects we present a framework for a definition towards social robots.

1. Introduction

In the last five years, research in the field of social robots has greatly developed and can be seen as an established interdisciplinary undertaking. Many computer science laboratories at various universities investigate this phenomenon of socially behaving robots. Form, function, and context of robots all have an effect on each other and therefore various relations have to be considered to understand human-robot interaction (HRI). Here we focus on the triadic relation of form, function, and context in communications with a robot.

Up to now, several definitions of social robots with different statements about the features were presented. We argue a social robot is perceived as a social entity because of the attributions human beings do automatically – that is anthropomorphism. We have to understand form, function, and context of social robots to control and to reinforce the intensity of social attributions towards robots. Therefore, designing HRI is to vary the relations between behaviour and appearance within a situation which influence the interaction with a human being.

First, in order to understand the phenomenon of social robots we first refer to the history of robotics and present the most common definitions of social robots to compare the main concepts (Section II). In Section III we contrast the definitions of robots with social robots to find out the core purpose of social robots. Section IV refers to social attributions towards robots. We introduce briefly the *Theory of Product Language* in Section V to analyse some of the most important relationships emerging between form, function, and context. In conclusion, we discuss the insights and potential impact of the paper in Section VI.

2. Related Work

The idea of robots as artificial beings is hundreds of years old: The original meaning of automaton implies autonomous beings having the ability to move on their own [1]. Vausanson's flute and tabor player and Wolfgang von Kemepelen's famous chess player, the Turk, designed in the mid 1700s, are early encounters between lifelike forms and mechanical machines. This machines invoked on people's projections and expectations due to the lifelike behaviour displayed by their aesthetic form.

First, we illustrate definitions of robots. Afterwards we present four often cited definitions of social robots. The presented concepts originated from a broad empirical background. All of them are necessary to understand the differences between robots and social robots.

2.1 Definitions of Robots

The term of *robot* has been coined in Karel Capek's play R.U.R. (Rossum's Universal Robots) in 1921 and also the term Robotics was first used within the short stories written by Isaac Asimov in the 1940s.

The progress in technology in the 1950s-70s formed the basis to design machines with a more complex behaviour. In 1958, while discussing about Asimov's stories, Devol and Engelberger founded Unimation, the first company for Robotics. General Motors used the first Robot named Unimate on their assembly lines. In general, definitions of robots represent such basic tasks like assembling specific items on an assembly line. For example, the *Robot Institute of America* (RIA) defines the robot as a reprogrammable, multifunctional manipulator designed to move parts, tools, or specialized devices through various programmed motions for the performance of a variety of tasks.

Another explanation was used by Kaplan [2] in the context of robots as everyday objects. A robot is an object that possesses three properties: (1) It is a physical object, (2) it is functioning in an autonomous and (3) in a situated manner. This means a robot is a programmed physical entity that perceives and acts autonomously within a physical environment which has an influence on its behaviour. In addition, the robot is situated, i.e. it manipulates not only information but also physical things.

Furthermore, the *International Federation of Robotics* (IFR) distinguishes two principal services by robots: (a) servicing humans (personal safeguarding, entertainment etc.) and (b) servicing equipment (maintenance, repair, cleaning etc.) and focussing on a task. A *Service Robot* is "A robot which operates semi or fully autonomously to perform services useful to the well being of humans and equipment, excluding manufacturing operations." The IFR did not focus on the interaction between humans and robots, but in contrast Engelhardt brought especially humans on focus: he defines *Service Robots* as systems that function as smart, programmable tools, that can sense, think, and act to benefit or enable humans or extend/enhance human productivity [3].

2.2 Definitions of Social Robots

Initially social robots were inspired by biology. They were basically used to study swarms or the behaviour of insects [4]. However, later approaches treat the interaction between humans and robots.

The term *social in this case* represents the fact that there are two or more entities within the same context [5]. In contrast to service robots social robots were explicitly developed for the interaction of humans and robots to support a human-like interaction. For our approach to understand social robots, we basically collected four familiar positions of social robots: Duffy's social robot, socially interactive robots by Fong et al., Breazeal's sociable robot, and finally a design centered approach presented by Bartneck et al.

A. The Social Robot

Duffy distinguishes between Social and Societal Robots [10]. Social robots interact which each other (multi-robot interaction) while Societal Robots interact with human beings. He presents a social robot whose architecture is constructed on four consecutive layers [6]: (a) The physical layer: The robot has a form in an environment and this is steered by primitive motor activities. (b) The reactive layer treats fundamental sensorical reflexes to a (c) deliberative layer which is a Beliefs-Desires-Intentions (BDI) architecture. (d) Finally, the *social layer* is calculating the communication via an *Agent Communication Language* named Teanga. Both, layer three and four are complex, but the difference is that layer three treats complexity from an individual perspective. That is the basis of layer four which implies the concepts for a complex social behaviour of robots.

B. Socially Interactive Robots

According to an extensive survey of social robots Fong et al. [4] compiled several aspects of socially interactive robots. From their point of view, "Social robots are embodied agents that are part of a heterogeneous group: a society of robots or humans. They are able to recognize each other and engage in social interactions, they possess histories (perceive and interpret the world in terms of their own experience), and they explicitly communicate with and learn from each other" [4].

Therefore, the socially interactive robot requires some specific capabilities: it has to be able to express and perceive emotions, communicate with high-level dialogue, learn and recognize models of other agents. Furthermore, it has to be capable of establishing and maintaining social relationships, using natural cues (gaze, gestures, etc.), and exhibiting distinctive personality and character. Finally, the robot may also develop social competencies.

C. The Sociable Robot

For Breazeal [7], a sociable robot is able to communicate with us, understands and even relates to us, in a personal way. It should be able to understand humans and itself in social terms. In turn, human beings should be able to understand the robot in the same social terms – to be able to relate to the robot and to empathize with it. Such a robot must be able to adapt and learn throughout its lifetime, incorporating shared experiences with other individuals into its understanding of itself, of others, and of the relationships they share. In short, a sociable robot is socially intelligent in a human-like way. To reach this aim of a sociable robot, Breazeal states (a) a requirement for embodiment in a situated manner, since social experience depends on symmetrical environments where entities interact with each other – may it be real or virtual. (b) A sociable robot has to have lifelike qualities because humans anthropomorphize technology and we tend to interpret behaviour as being intentional. (c) Also, a robot must be capable of identifying who the person is, who it is interacting with, what the person is doing, and how the person is doing it. *Theory of Mind* and empathy are necessarily notions to design human-awareness. (d) Being understood means, the human needs to be able to read the activities (expressions, mimic, etc.) of the robot. Finally, (e) according to [8] the robot has to learn socially situations that shape the robot's personal history by imitation or mimikry. Breazeal's perfect sociable robot behaves like a human following the term *Computational Social Psychology* [9].

D. Design-centered Approach

Within the design-centered approach proposed by Bartneck and Forlizzi [10], a social robot is an autonomous or semi-autonomous robot that interacts with humans by following the behavioural norms expected by the people with whom the robot is intended to interact. Their definition presupposes three conditions: the robot has to be autonomous, depending on the case it has to interact cooperatively or non-cooperatively, and it has to recognise human values, roles etc. Bartneck and Forlizzi describe social robots with five parameters: (a) abstract, biomorphic, or anthropomorphic form, (b) unimodal to multimodal communication channels, (c) the knowledge about social norms, (d) the degree of autonomy, and (e) causal to non-causal interactivity. Finally, they created a guideline which outlines the components the robot should comprise: First, the form should match the expectations of a user. Second, the robot should communicate verbally and nonverbally with all modalities. And third, the robot has to be able to take human social norms into consideration.

3. Towards a Definition of Social Robots

All discussed conceptions of social robots only contain aspects about form and function. Within the definitions of industrial robots the form is, however, not mentioned. Thus, there is a difference between robots and social robots relating to form. Duffy, Fong et al., Breazeal, and Bartneck et al. argue that embodiment and form of social robots are important aspects. Users have different expectations due to the aesthetic form of robots. In our opinion aesthetic form communicates social cues and signals and the behaviour of a robot is mediated somehow through its physical form.

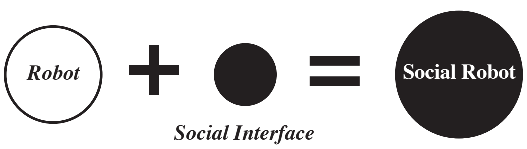

Figure 1. A social interface creates a social robot.

In comparison with a robot (see 2.1) a social robot combines technical aspects as well as social aspects – but the social aspects are the core purpose of social robots. The robot is not a social robot per se, it needs specific communicative capabilities to become a social robot. First, it implies the robot to behave (function) socially within a context and second, it implies the robot to have an appearance (form) that explicitely expresses to be social in a specific respect to any user. From this point of view, a *social robot* contains a *robot* and a *social interface* (see Figure 1). A *social interface* encloses all the designed features by which a user judges the robot as having social qualities. In principle, it is a metaphor for people to interact naturally with robots. This is an analogy to the desktop metaphor on computers where people treat the things in the graphical user interface like in their real world – due to the metaphor they have an idea on how it works.

4. Social Attributions towards Robots

Human beings perceive signals and cues of the robot, including contextual information and subsequently attribute social qualities. This is comparable to a child, using a puppet as social partner. It can attribute living capacities towards the puppet, and yet at the end of playing, the puppet becomes only an object again. In this case attributions are triggered and reinforced by the appearance of the puppet and specific situational schemata. This kind of projective attitude of humans towards objects has also been proved by Turkle [11]. She investigated the social action towards machines. Thereby she found that humans especially children attribute lifelike qualities to simple electronic toys as even their calculators. However, here we investigate a rather complex situation, the communication with a social robot, understood as a reciprocal undertaking. A main distinction for describing and explaining the human action in sociological theory is the concept of individuality. The idea of the individual originates and traces the human acting in its rationality which is the substantiation of the responsibility for the own acting. For example, Webers [12] concept of social human action emphasizes the aspect of its reflexivity. As a leading element, he defined action from behaviour by specifying the definition to *rational* action. Social actions take this into account and refer to further or former actions and reactions, performed by indiviuduals. This implies the expectation of the others' action. The follow-up of interactions is a sequence of social actions, which are highly reactive, and therefore are most complex and advanced. The modifications of these sequences result from dynamic interrelations, caused by rational interference. Weber concludes: "Social action is an action, which is in its appropriate sense, given by the actor, directed towards others and therefore it is oriented in its procedural toward the partners" [12, translation by the author]. The fact, that human beings actively give reason to their acting, has also been analyzed by Schütz [13]. He elaborated the human capability in ascribing sense to things: The rational understanding allows us to distribute an individual and significant meaning to situations and objects.

This is consistent with the theory of anthropomorphism [14]. Humans attribute human-like qualities to nonhuman agents depending on several parameters like appearance and social context – and consequently expect human-like actions. For example, if subjects play a prison dilemma game against different robots they attribute intentions to the opponent depending to the human-likeness of the robot [15]. This idea of attributing individuality is closely connected to the concept of social ascriptions in the tradition of sociological theories of human action, communication, and behaviour. Therefore, we need to understand how form, function, and context influence the attributions of life-like qualities.

5. Form, Function, and Context

The *Theory of Product Language* serves as a tool to analyse what kind of qualities people attribute to robots.

5.1 A Theory of Product Language

From the perspective of design theory objects not only sig-

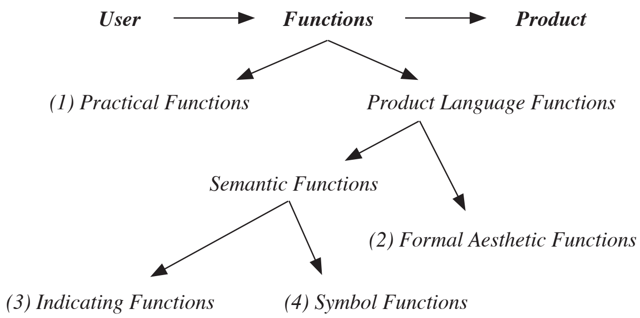

Figure 2. The functions of products.

nify their basic function – they also convey different meanings. The *Theory of Product Language* [16,17] which is based on symbolism [18] investigates the meaning of products in accordance with cultural contexts (e.g. technological, economical, ecological, social issues, lifestyle). Here, the functions of a product relate to the effect a product has on a user. The theory distinguishes between four functions that every product, and consequently every robot, possesses: the practical function, formal aesthetic functions, indicating functions, and symbol functions (see Figure 2).

(1) Practical functions represent the intended use of products. For example, the practical function of a car is driving, the practical function of a chair is sitting on it.

(2) Formal aesthetic functions give a grammatical structure to the visual elements: form, material, color, and surface. The knowledge of these functions is based on *Gestalt* principles, order, and complexity on a syntactical level without meaning.

(3) Indicating functions represent the information of how to use the product's features. "A sign indicates the existence – past, present, or future – of a thing, event, or condition" [18]. When a user perceives an indication he relates to the product's functions and meaning to his knowledge and experience within a context. An indicating sign mediates between the human being and technology and supports the understanding of the practical functions. Therefore, these signs contribute to the ease of use and user-friendliness. Furthermore, there is a distinction between natural and artificial signs. For example, a fall of temperature shown on a barometer or a ring around the moon are natural signs that it will be raining soon. But the colour 'red' on a traffic light is an artificial sign and it indicates 'stop walking' in a specific context because of human convention [18].

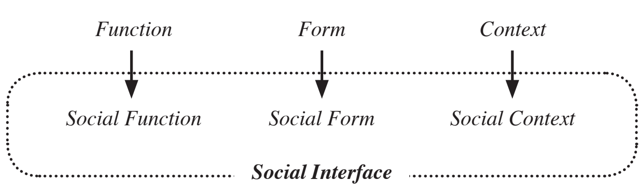

Figure 3. Social aspects of form, function, and context.

(4) Symbols are vehicles for the conception of objects. In talking about things we create conceptions of them, not the objects themselves; and it is the conceptions, not the objects, that symbols directly 'mean'. While indicating signs denotate the concrete object, symbol functions convey all mental ideas relating to the product. Thus, symbols express cultural and social values and they describe the context based on cultural and social backgrounds. Lifestyle, brands, era etc. are all aspects of symbol functions.

To consider the results of *Theory of Product Language*, the appearance of a robot conveys information about technical functions and behaviour as well as contexts. Therefore, we have to reflect about the relations between form, function, and context of social robots.

5.2 Form, Function, and Context of Social Robots

Form, function, and context are the parameters which characterize a robot from a holistic point of view. Every robot has a aesthetic form. Also, every robot has different kinds of behaviour, i.e. varying functions. Finally, the robot with its aesthetic form and functions is within various contexts whereby context also defines the problem [19] which is the need for specific functions and a specific form wihtin a specific context.

As mentioned, there is a major difference between robots and social robots. To understand not only robots but social robots we have to consider the social aspects of form, function, and context – they define the social interface in more detail (see Figure 3). This leads to the question, what are social forms, social functions, and social contexts?

A. Social Forms of Social Robots

The social aspects of the robot's form are the elements which contribute to the human-robot communication. For example, without any face the robot would be faceless – that means a kind of anonymous [20]. But by having a face, the communication changes fundamentally: an expressive face indicating attention [21] and imitating the face of a user [22] makes a robot more compelling to interact with. The design of a face is an important issue in human-robot interaction because it has been shown that most non-verbal cues are mediated through the face [23]. Thus, with a face the robot is able to send social signals, i.e. non-verbal signals like displays of emotion and the robot is able to be attentive just by looking at something or someone. Also human-likeness mainly depends on the perception of a face within a robot [24] and the more human-like a robot is the more people expect the robot to interact in the same way as humans do. So, a face is one form that facilitates social interaction with a human being.

B. Social Functions of Social Robots

Function is unmistakably associated with action. The function of a product is to produce action or provide the resources for action [25]. But what actions does the product enact and how?

All aspects which compute any artificial social behaviour of a social robot are part of social functions. For example, artificial emotions, BDI-architectures, joint attention mechanisms, and modules for speech recognition and production are functions that produce and alter social interaction.

C. Relations of Social Forms and Social Functions

Various relations exist between social forms and social functions in both directions: First, any implemented behaviour needs to be displayed through some kind of aesthetic form. For example, if the robot's architecture is computing artificial emotions like happiness within a face-to-face conversation they have to be displayed through a face or a body which is simply an aesthetic form. The crucial point is whether a user is able to read the emotion displayed by the face or not. The ability to read social functions, i.e. social behaviour mainly depends on the formal aesthetic functions and on how iconic they are to human expressions. Hence, social functions and social forms should match the people's expectations in order to influence the predictions the user makes – with a functional designed robot it is impossible to express human facial expressions and consequently emotional displays.

Second, forms are indicating functions and consequently behaviour. In human communication aspects like attractiveness or baby-faced features [26] influence people to expect a specific behaviour and therefore change their attitudes towards a person.

For example, anthropomorphism deals with the relation between form and function. Anthropomorphism is defined as the attribution of human-like qualities to non-human agents or objects [14]. According to v. Foerster [27] we anthropomorphize because this allows us to explain things we do not understand in terms that we do understand, and what we understand best is ourselves as human beings. This is consistent with the familiarity thesis [28] which claims to understand the world based upon a mental model of the world that we are most fimiliar with it. An important variable that influences anthropomorphism is similarity to a human being. The more

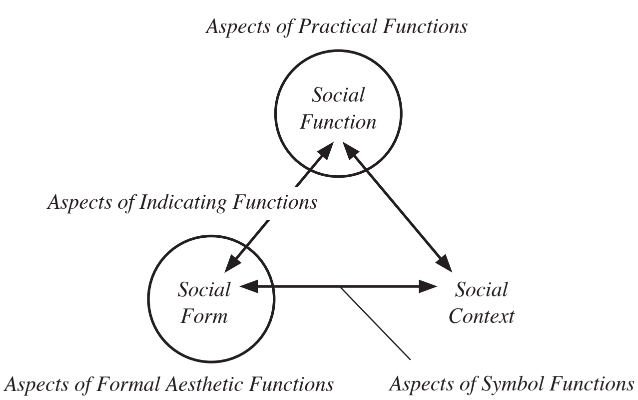

Figure 4. Relations and aspects of social form, social function, and social context.

human attributes a robot has, the more it will be perceived as human-like [24] and the more similar a form is to a human, the more people anthropomorphize the machine [24,28]. Thus, it implies that human attributes and human-likeness influence specific expectations a user has regarding the social behavior of the robot.

D. Social Contexts of Social Robots

Aspects of social contexts determine form and function. An application is a context of a robot and influences the function. Within an application a robot should be able to perform all necessary tasks to maintain the expectations of a user. But the robot does not have to be able to do things outside of its intended application, because in general people do not expect the robot to do things it is not prepared for. Therefore, applications are one criterion to decrease complexity and to determine the tasks of social robots.

Furthermore, role schemata [29] are an interesting concept to fulfill expectations of users within a context. For example, Hayes-Roth [30] showed that if an agent looks like a bartender, people expect him also to behave like a bartender. That means, the agent does probably not need to have knowledge about several foreign languages, but he needs knowledge about his specific field and of course he needs to know how to talk to people and how to treat them. Social roles interrelate with aesthetic form aspects and the agent's behavior within a context.

In summary, social form, social function, and social context represent categories which can serve as a design guideline whose aspects have to be considered when designing social robots. Figure 4 depicts the relations of social form, social function, and social context with its specific aspects by the *Theory of Product Language*.

6. Discussion and Conclusion

We addressed the aspects of the social interaction between a human user and a social robot. Our attempt has been to provide a framework for a more holistic view on this matter. For this purpose we addressed some of the main discussed topics within the community of social robots and organised them into the aspects and relations of social forms, social functions, and social contexts.

Designing social robots presupposes creating and reinforcing social cues which support social interaction with human beings. To interact socially with a robot means to communicate by referring to social behavioural patterns. Therefore, we argued that the distribution of meaning is a unique human quality. As we can attribute human-like qualities to puppets and even to calculators [11], it is up to human beings to act socially and therefore make robots to social interaction partners. The ability to accurately interpret the partners' action accurately is a human social skill. This aspect does not imply that the robot itself has to be social – but it implies the robot has to be able to provide social cues towards the people who create their interaction partner in their mind and who have expectations how the robot will behave in social contexts.

Social forms, social functions, and social context all have an effect on each other and therefore various relations have to be considered to reinforce and to control social attributions. (see Figure 4). Thereby we used the *Theory of Product Language* [16, 17, 18] as an assistant semiotic tool to understand what aesthetic forms indicate and convey (as mentioned above in Section 5.1).

With the term of social forms we addressed all aspects of the robot's shape that support the social interaction between humans and social robots. Aspects of social functions contain concepts that generate a social behaviour. Furthermore, a social context implies all the aspects where, why, and when there is any specific social interaction between a human being and a robot. When designing social robots we have to consider social forms, social functions, and social contexts which create the social interface.

Finally, the discussed topics led us to the following definition to design social robots: A *social robot* is a robot plus a *social interface*. A *social interface* is a metaphor which includes all social attributes by which an observer judges the robot as a social interaction partner.

7. Acknowledgements

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