Creating Service Robots for and with People: A User-centered Reflection on the Interdisciplinary Research Field of Human-Robot Interaction

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Abstract

User involvement is a widely accepted principle in the development of usable and acceptable technology. However, it is still a vague approach in the interdisciplinary research field of Human-Robot Interaction (HRI). This paper gives an overview on the nature of user involvement in HRI research and how an interdisciplinary development of service robots can be achieved in the requirement analysis phase as well as through a user-centered evaluation procedure. The paper closes with a reflection on the interdisciplinary nature of HRI as a research field. It shows that in three phases of a researcher's career (orientation, positioning, and stabilizing and expanding) a tendency towards the discipline and away from interdisciplinary work can be observed and that the forth phase (attachment) needs to be strengthened, independently of disciplinary or interdisciplinary approaches.

1. Introduction

Human-Robot Interaction, a quickly growing research area, has only evolved in the last 20 to 30 years. As the term suggests, the main focus is on the interplay between a human and a robotic agent, where the interaction can be verbal and non-verbal (Dautenhahn, 2007). Nevertheless, so far no official and commonly agreed on definition of HRI exists, as there are many different ways in which humans can interact with a robot (e.g. communication via speech, gestures or symbols). Fong et al (2001) defined HRI as follows: "Human-robot interaction (HRI) can be defined as the study of humans, robots, and the ways they influence each other". Several disciplines are needed to study this interaction: robotics, computer science, social sciences, psychology, etc. to name a few. Therefore, Human-Robot Interaction research is a multidisciplinary area originating from the idea to combine robotics with humanities to *“understand and shape the interactions between one or more humans and one or more robots”* (Goodrich & Schultz 2007, 216). Already in 1992, Kidd argued that robotic system development needs a human factors perspective as *“there is, […] no logic in developing and using technologies such as robotic systems in a way that attempts to replicate the skills of the people who will have to use the system, if this leads to unsatisfactory work. Moreover, the human-centered philosophy offers the potential of a better way in which to introduce new technologies. It can also avoid creating the need for skills that do not exist.”* (Kidd 1992, 237). However, researchers entering HRI either from a robot-centered or human-centred perspective, are rarely aware of the full range of methods that can contribute to knowledge gain on the complex question how humans interact with robotic systems. The purpose of this paper is a collection, description, and discussion of relevant human-centered approaches to HRI research and a reflection of the interdisciplinary nature of HRI. It should guide researchers to potential social science inspired user-centered approaches and give indications how the research field is compounded.

2. Human-Robot Interaction research: The theoretical basis

As HRI is a rather young research field, theories in the sense of systematic and structured bodies of knowledge are still rather spare. However, developing, understanding, and applying theory is of particular importance, as it is for any other interdisciplinary research endeavour. A trouble current HRI research is facing is that similar as in Human-Computer Interaction research, even theories are “generative artefacts: things that are used (by people) to create other things” (Dix 2008, 192). In other words, existing theories from e.g. sociology, cognitive sciences and social psychology are used to explain, analyse, and design HRI and in some cases even to generate new theories.

Theoretical approaches inspired by action theory can be found more often in HRI than systems theory. The most prominent action theory representatives in the HRI research community are Reeves and Nass (1996) with the “Media Equation” which was also extended towards the (1) CASA (Computers as Social Actors) paradigm by Turkle et al. (2006), who was adding reflections on companion robots as (2) “Relational Artifacts”, and Suchman (2007) with her work on (3) Human-Machine Reconfigurations in her reissue of “Plans and Situated Action”.

The (1) *CASA paradigm* states that humans mindlessly apply the same social heuristics used for human interactions also for computers, because computers induce similar social behavioural attributes as humans. Considering that, it is claimed that social science theories can be used as basis to study human-technology interaction.

(2) The concept of *Relational Artifacts* describes robots (above all companion robots, i.e. robots mainly intended to serve as social interaction partner) as a new type of technical entity that can respond back to us in such a way that we experience this response as emotional as in human-human relationships. It is considered that these cues shaping companion robots this way are intentionally incorporated in their design.

(3) The concept of Human-Machine Reconfigurations discusses how humans and human-like machines "are enacted as similar or different and with what theoretical, practical, and political consequences". (Suchman, 2007, 1).

Another common approach in HRI research is to firstly explore human-human interaction and then trying to transfer findings to HRI paradigms and compare them against human-human interaction considered to be the golden standard (see for instance Weiss et al. 2011).

3. Requirement analysis and interaction scenario development

Traditional user-centred design approaches and approaches, such as participatory design and double-diamond design all have two things in common: they consider the target user in the design process with the aim to create user-friendly, usable systems. User-centered methods used at this stage are mostly qualitative and explorative in nature, such as focus groups, interviews, and so-called co-design workshops in which potential end-users and researchers use creative techniques such as story-boarding and mock-up building to communicate their ideas.

Typically, a requirement analysis phase ends with operationalizing results (e.g. "a big robot would scare me" into maximum robot height 150cm) followed by ranking requirements according to specific priorities and constraints (e.g. technical feasibility, utility of the system etc.). As a next step interaction scenarios are developed which serve as narrative stories and define the interaction with the robot. In parallel, scenarios help to communicate ideas between interdisciplinary researchers as well as between researchers and end users. The narrative aspects support the creation of common mental models and a shared vision of the final system. The personas (stereotypical target user description) and scenario approach originally stems from Human-Computer Interaction, but also entered the HRI research community (Robins et al. 2008, Zlotowski et al. 2011). In a final step the narrative scenarios need to be transferred into an implementation roadmap from the robot-centered perspective. In other words, how to compile hardware and software to achieve the expected outcome.

Two major challenges are involved in a user-centered requirement analysis in HRI: (1) The novelty of robotic systems and the lack of users' pre-experience and mental models of how a robot could actually be helpful for them; (2) the subsequent discrepancy between user expectations and technical feasibility; Different to other computer technologies do human-like robots encourage the formation of anthropomorphic mental models (Kiseler et al. 2005) and imaginations of future robots, which is mostly induced by science fiction (Bruckenberger et al. 2012).

4. Evaluation criteria: usability, user experience, and social acceptance

A variety of different user-centered evaluation criteria exist for HRI researchers. In the following, I will only briefly describe three of the most frequently addressed ones: usability, user experience, and social acceptance (section 4.1-4.3). After this description examples for different types of study methods are presented in section 4.4-4.8.

4.1 Usability as evaluation criterion

According to the ISO 92411-1:1998 standard, usability is "the extent to which a product can be used by specified users to achieve specified goals with effectiveness (task completion by users), efficiency (task in time) and satisfaction (responded by user in term of experience) in a specified context of use (users, tasks, equipments & environments)". In summary, usability is defined as the overall ease of use, describing how easy a user can interact with a system. In HRI research the main research question with respect to usability is: How well can a user accomplish a given task together with a robot? Typical measures taken are (1) task completion rates, (2) task durations, (3) error rates, and (4) success rates. Typical pitfalls when trying to measure usability are that (i) task durations can vary heavily between users and different robot platforms, (ii) human-robot interaction scenarios often offer too little flexibility to be solved in different ways, (iii) robots offer little user support in case error situations are happening, (iv) the possibilities for interaction with multi-functional service robots are hard to capture due to a lack of explanatory support by the system.

4.2 User experience as evaluation criterion

User experience is a multifaceted term that evolved from the research field of Human-Computer Interaction, which is also defined in ISO 9241-210. An HCI definition of user experience that can be suitably adapted for HRI research was coined by Alben in 1996: *"All the aspects of how people use an interactive product: the way it feels like in their hands, how well they understand how it works, how they feel about it while they're using it, how well it serves their purposes, and how well it fits into the entire context in which they are using it."* (Alben 1996, 4). In HRI the main research question with respect to user experience is "How positively does the user experience the interaction with the robot?" Typical measures are (1) engagement, (2) social presence, (3) fun, (4) anxiety. Typical pitfalls when measuring user experience in HRI are that (i) experience changes over time; robots create a so-called novelty effect of the user which vanishes over time, (ii) appearance and behaviour of the product can lead to different impacts on the experience, (iii) a positive user experience does not necessarily imply high usability and the other way around.

4.3 Social acceptance as evaluation criterion

Social acceptance can be distinguished in two different basic understandings: (1) user acceptance of a technology as social actor, e.g. the individual willingness to interact with a robot as tour guide or (2) the acceptance of a robot on the societal level, e.g. social acceptability of robots as co-workers in factories (Weiss 2010). In most studies the first understanding is addressed and measures consider aspects such as (1) user willingness/ intention, (2) attitude towards using the robot, and (3) self-efficacy. The biggest pitfall in assessing social acceptance is that it differs in lab and field trials (see Mirnig et al. 2012). More details on this aspect can be found in section 4.5.

4.4 User studies and controlled experiments

User studies are performed in order to provide empirical evidence answering concrete research questions and/or test hypotheses. Such user-involving evaluations are often task-based and the user behaviour while performing these tasks is observed and measured by a researcher. It is important to distinguish user studies from controlled experiments. Though both are working with representative target users, the term user study is the general umbrella term, which does not necessarily imply that it is an experiment, but only that a system is studies with target users. Experiments test controlled hypotheses, for which a specific sample size is needed in order to achieve statistically significant results. Therefore experiments need a specific study design in controlled conditions in order to be replicable. User studies can also be of purely exploratory nature and for instance explore how many usability problems occur when a number of representative users are performing a specific task with the robot. User studies can be performed in the lab or in the field (often also referred to as “in the wild”) where users are encountering the robot in a more intuitive set-up (see section 4.5 for details).

Moreover, in HRI research two specific, prominent techniques need to be mentioned Wizard-of-Oz (WoZ) studies and video-based studies which are used in cases where studying the interaction with an autonomous robot is hardly doable. In WoZ studies (see Riek 2012) an invisible human “wizard” is simulating system features which are not actually implemented. This approach involves several advantages besides the fact that less resources need to be invested in implementation: (1) the interaction is safe and always in control of the wizard, (2) features which cannot be provided autonomously by the robot can be studied nevertheless, (3) the whole study can be pre-scripted and controlled. Video-based studies are often used in order to achieve bigger sample sizes. Users are shown videos of human-robot interaction scenarios and questioned afterwards about what they think of or how they would react to/in the watched situation. Woods et al. (2006) showed that video studies can reveal comparable results to actual user studies. However, clearly this type of study is not suitable for all types of research questions, as no actual interaction is taking place (results can only be interpreted based on the Theory of Mind (Leslie et al. 2004). In general, both techniques are critically debated in the HRI research community with respect to validity. Instead, studies with fully autonomous systems are considered the gold standard.

4.5 Expert evaluation techniques

Expert evaluation techniques are used to mainly detect usability problems in a low-cost and less effort-intensive way than user testing. In this type of evaluation several experts examine the interaction with a robot and judge it in compliance with general usability principles or guidelines. These techniques are also often called "usability inspection methods" and the most common approaches are heuristic evaluations (Weiss et al. 2010a) and cognitive walkthroughs (Weiss et al. 2010b). However, the biggest challenges with these techniques is identifying the appropriate experts and the right heuristics/guidelines.

4.6 Self-reporting techniques

Self-reporting measures subsume all types of techniques used to collect impressions of users after interacting with a robot, such as questionnaires, interviews, and focus groups. Standardized questionnaires used for HRI research are already established and validated, such as the Godspeed questionnaire series (Bartneck et al. 2009) for measuring anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety; the NASA-TLX questionnaire (Hart et al. 1998) for measuring perceived workload, and the NARS questionnaire (Negative Attitude towards Robots Scale) measuring negative attitude toward situations of interaction with robots, negative attitude toward social influence of robots, negative attitude toward emotions in interaction with robots (Nomura et al. 2006). Self-reporting measures are easy to integrate into a study design, as they are simply attached after the interaction experience. However, one has to be aware of the danger of socially desired answering behaviour and the fact that the responses are always a reflection of user experiences and never an immediate reaction.

4.7 Implicit measurements

Another approach are so-called implicit measurements. We can distinguish between physiological measures, such as eye-tracking, heart-rate variability or functional magnetic resonance imaging, and association measures measuring subconscious attitudes, such as implicit association tests (Greenwald et al. 1998). Independent of this distinction, all these measures need careful interpretation. An increased heart rate for instance may be an indication for an increased stress level, but also for increased concentration on a complex task. Moreover, even if an implicit association test reveals for instance “fear” as automatic response towards a robot, does not mean that on a reflective level a user cannot decide to like the robot anyways after interaction.

4.8 Studying robots “in the wild”

Studies in “in the wild”, meaning outside of controlled laboratory environments (e.g. in public places, private households, and factories), are very challenging, as it is harder to predict how the interaction will turn out. Research is of high societal importance, hence it is essential to involve the general public and this is why studies in public places are particularly suitable for sharing knowledge and experiences with a great number of people (MCKenzie 1996). For field trials, always two aspects need to be considered: First, we strive for field data which are necessary for realistic insights, as approaches in the field are more open and playful; people are not constantly aware of the study situation and do not feel obliged to please a researcher. All of this makes data collection in the field very interesting, but enforces a less structured and scripted approach. Second, we seek active contact between researchers, technology and the target group of potential users of advanced robotic solutions. Such close contact can contribute to raise people’s awareness of robotic research projects and may even contribute to a wider understanding and acceptance. However, from a technology-centered point of view, field trials incorporate enormous risks: What if an autonomous system harms a user in a household trial when no researcher is present? What if the robot breaks during a field trial if no researcher is present? How can we ensure that the system is performing the way that was intended? To summarize for user-centered design approaches, field trials can be considered most informative, but with the trade-off that a lot of technical and methodological challenges need to be overcome.

5. The interdisciplinary nature of HRI as research field

While HRI is considered to be an interdisciplinary field, if we take a look on stereotypical statements from fellow HRI researchers[1] (see Weiss 2012) and analyse them in conjunction with the “epistemic living spaces” concept developed by Felt et al. (2009) we see tendencies towards disciplinary thinking. The concept of Felt et al. (2009) is based on the coproductionist

[1] Contrary to the work of Felt et al. we cannot base our work on actual interview and focus group data, but we want to reflect on often mentioned statements by HRI researchers, which can be considered as stereotypical descriptions.

approach by Jasanoff (2004), which stresses the intertwinedness of science and society. Similar to Felt et al. we take "a person-centered view to draw the attention to the individual and/or collective perceptions and narrative re-constructions" of the knowledge production in the research field of HRI. The stereotypical statements presented in the following can be considered as often-heard informal statements in the community. These statements only serve as a starting point for reflection; therefore its "degree of reality" is not of utmost relevance. To verify the assumptions exploratory interviews with HRI researchers in various stages of their career would be required. The statements are intentionally formulated in a provocative manner in order to enable a discussion. For each statement two viewpoints are presented: the potential point of view of a user-centered researcher (which subsumes disciplines such as psychology, social sciences, communication sciences, etc.) and the potential point of view of a robot-centered researcher (which subsumes engineers, computer scientists, software developers, etc.). This approach was chosen to depict the "creative tension" of disciplines in the field.

5.1 Coping with different knowledge

The first aspect that should be discussed is that in interdisciplinary research one has to cope with the fact that not everybody has the same background and knowledge on a common research topic/question. This can lead to the personal perception that one is missing skills to perform interdisciplinary research on one's own (only very few people are interdisciplinary on their own, as little have finished two polarizing studies and even then discursive approaches are more fruitful for complex research fields, such as HRI, than single person projects). Stereotypical statements for this are:

User-centered researcher: *"I am now taking this Stanford AI class, in order to know what roboticists are doing."*

Robot-centered researcher: *"I have read this social science book to know how to compile a questionnaire for my user study."*

However, what do these two statements tell us? Firstly, it shows us that interdisciplinary research is challenging for young researchers, as they cannot get all the tools they need during their scientific education. Secondly, it shows us that HRI researchers can have the feeling that they need to have the full knowledge space from the robot to the user pole. It can be assumed that young HRI researchers are missing " 'guiding' maps that enable them to identify central epistemic, social and institutional orders relevant in their specific environment and that support the creation of a tacit understanding of what is expected and needed to foster their own career." (Felt et al. 2011, 6) Thirdly, it shows that HRI research is more perceived as a subject/discipline, which has to be understood completely and not as single disciplines contributing to a common research question. This aspect of coping with different knowledge can be considered as the orientation phase according to Felt et al. (2011).

5.2 Demonstrating skills

The next aspect shows a similar tendency, namely that at a later stage young researchers seem to develop the feeling that they have to demonstrate that they can "compete" with researchers from the other disciplines. Representative Stereotypical statements for this aspect are:

User-centered researcher: *"I will demonstrate them that also social scientists know how to program."*

Robot-centered researcher "*I will demonstrate them that it does not need a psychologist to conduct an experiment."*

This aspect of demonstrating skills can be considered as the positioning phase according to Felt et al. (2011, 10), which "can be characterized as the early stage researchers' attempts to find a place in research, to develop an adequate epistemic living space, to realize who they are and what they stand for". However, instead of demonstrating their disciplinary knowledge and their skill to conduct interdisciplinary research, they try to demonstrate skills of the "competing pole". In a later phase positioning attempts are also made by demonstrating the personal (disciplinary) contribution to the research field. Representative stereotypical statements for this are:

User-centered researcher: *"Without a study with actual users it's not valuable for HRI."*

Robot-centered researcher: *"Without a study with a real, autonomous robot it's not valuable for HRI."*

Statements like this can be seen as the development of "traditional research myths", which indicate the existence of a scientific discipline. Researchers try to claim the ownership on specific research problems and above all how to address/solve them. This can also mean to convince researchers from related disciplines (e.g. social scientists convince psychologists or engineers convince computer scientists) to follow the same strategy in a research project in order "to meet the ideological and programmatic requirements, while keeping them largely out of epistemic decisions" (Felt et al. 2011).

5.3 Institutional aspects

The aspect of creating "scientific unions" as mentioned above, even gets stronger in later phases of a researcher's career, the phase, which is coined as "stabilizing and expanding" by

Felt et al. (2011). The difficulty for researchers who did their PhD in an interdisciplinary field normally is that they are missing publications in relevant journals and conferences and that there are little jobs, which meet their qualifications. In many cases PhDs then change to industry or do a postdoc in their traditional field (e.g. machine learning, cognitive sciences, etc.). The conditions for HRI researchers are already improving, there are journals, conferences, and job positions, which explicitly search for HRI researchers (which however are in many cases more suitable for technical study branches), but this again demonstrates that HRI more and more develops to be a discipline on its own. Representative stereotypical statements for this phenomenon are:

User-centered researchers: *"If we now want to get project money we need to focus on social acceptability and ethics".*

Robot-centered researcher: *"If we now want to get project money we need to focus on cognitive systems and brain interfaces".*

Nevertheless, also senior researchers in HRI try to stabilize their activities in order to have a "safe ground from which unknown territories may be explored" (Felt 2009) by coupling disciplinary aspects in their future research agenda.

6 Conclusion

The reflection on stereotypical HRI researcher statements (at different levels of seniority) revealed 3 different phases: orientation (coping with different knowledge at the beginning of the PhD), positioning (demonstration skills during the PhD), and stabilizing and expanding (institutional aspects in the postdoc phase). Many other aspects of the coproduction of scientific and societal agendas were intentionally not included in this discussion (e.g. national and international research funding schemes and framework programs, cultural and institutional differences in an international research field etc.) to focus on the key aspect: Is the HRI community facing the challenges of interdisciplinary work or are is it slightly moving towards the development of an own discipline? To my personal conviction, the question the community has to ask itself is whether it wants to teach our students the methodological competence to work as interdisciplinary researchers and develop an attachment to interdisciplinary work or if it wants to pursue the direction towards an HRI research discipline that demands for unified methods, specific HRI competences, taught in master course, HRI doctoral colleagues, professorships, and text-books. Both directions are worth-while, but for a flourishing HRI research community it will be relevant to quickly make a decision in order to support the new generation of researchers. Currently we are lacking efforts in one phase of interdisciplinary work in HRI, which is coined “attachment” by Felt et al. (2011). This phase should happen after the orientation phase and give students “the normative imagination of [...] knowledge production”. In this phase it is of utmost relevance to give young researchers the right tools and methods, which could be both the techniques to work interdisciplinary or specific HRI tools.

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