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Human-Centered Design in Human-Robot Interaction Evaluating User Experience and Usability

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Abstract

Social robotics is a fledgling field with a lot of potential. For several decades, it was a concept defined by research and theoretical approaches. Robots have gradually found their way into various aspects of our society as scientific and technological breakthroughs have allowed them to do, and they are now ready to leave the industry and enter our daily lives. In this regard, user experience is critical to ensuring an effortless and natural connection between robots and people. This study concentrated on the user interface approach in terms of a robot's embodiment, focusing on its motions, gestures, and dialogues. The goal was to examine how robotic platforms and people interact, as well as what differences should be considered while building robot activities. To accomplish this goal, a quantitative and qualitative investigation based on actual conversations between many human beings and the artificially intelligent platform was done. The information was acquired by capturing each interaction and having every participant fill out a questionnaire. The findings revealed that participants enjoyed communicating with a robot and considered it engaging, which resulted in increased trust and pleasure. However, the robot's response delays and faults created dissatisfaction and disconnection. The study discovered that adding embodiment into the robot's design increased its user experience and that the robot's personality and conduct were important elements. It was established that robotic platforms, as well as their look, movements, and mode of communication, had a significant impact on user perception and interaction.

Keywords: Human-robot interaction, Evaluation methods, Frameworks, Human Centered Design

1. Introduction

Intelligent machines are used in Industry 4.0, and a greater number of robots are being introduced to the workforce to increase operational quality and productivity. However, humans are still required to ensure high flexibility in processes and to respond proactively to developing market needs and growing requests for product customization. Human-robot interaction (HRI) is an investigation of how people engage with robots, with an emphasis on how they act and their feelings toward the robots' physical, technological, and interactive capabilities. HRI encompasses a wide range of research topics, including educational technology (Akram et al., 2021a; Ramzan et al., 2023), engineering, psychology (Audi et al., 2021; Akram & Abdelrady, 2023; Ramzan et al., 2023), design, sociology, anthropology, and philosophy. Interaction and cooperation between robots and human beings are currently open topics in any application scenario, but especially in manufacturing. The use of robots in the production process can reduce both physical and cognitive labor. Today, the majority of commercial and scientific study on HRI and HRC is heavily "robot-centered," focusing primarily on technical difficulties and technological solutions without considering the human perspective. Human safety is frequently considered (Elisa Prati a, 2021).

In the past few years, robotics has broadened its scope, from domestic robots to robots targeted at improving people's quality of life. Human-robot interaction (HRI) effectiveness in social robots is a significant challenge. User Experience is an important notion in the design of both physical and digital items such as gadgets, software, websites, and mobile apps (Abdelrady & Akram, 2022; Audi et al., 2022). It can be used to improve cooperative robotics systems, the framework of human-robot dialogue, or thinking about application design. Researchers have investigated the significance of evaluation strategies or methodologies in Human-Robot Interaction (HRI). They recognized numerous sorts of measurements, including qualitative and quantitative, objective and subjective, and stressed the need to combine methodologies to increase the insights produced from UX evaluation. Research shows that the presence of social robotics increases empathy, collaboration, and trust among people, and reduces racial biases. Designing a robotic platform with autonomy in UX terms will make robotic applications more user-friendly, avoiding user exhaustion or boredom during interaction (Ana Corrales-Paredes, 2023).

Robotic technology's recent and quick growth has brought robots closer to positions and applications that require direct connection to individuals in their everyday contexts such as residences, educational institutions, hospitals, and museums. As a result, interaction between humans and robots has grown more socially placed and multifaceted. We claim that emotional and social levels of engagement play a key role in an individual's understanding of and overall satisfaction with any technology or artifact (Ramzan et al., 2023) and that this link is more prominent, distinctive, and entangled for interactions with robots. Research strongly suggests that interaction with robots is complicated and elicits strong social and emotional reactions. This raises the fundamental question of whether specific attention is required for HRI evaluation and whether standard HCI methodologies may be easily applied to HRI (Alain Karsenty, 2002) .

1.1. Objectives

- Investigate techniques for creating flexible robotic devices that can react to personal user preferences and behaviors.
- Explore emotional and psychological elements that affect user perception during encounters with robots.

1.2. Statement of the problem

The incorporation of robots into numerous elements of human life is fast progressing within the field of interaction between humans and robots (HRI). However, the efficacy of these interactions is determined by the extent to which Human-Centered Design (HCD)

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approaches are used to achieve the best User Experience (UX) and Usability. Despite growing curiosity in this interdisciplinary field, there is still a lack of understanding on how to methodically develop and assess robotic systems that priorities human demands, preferences, and psychological well-being. The existing body of research lacks a thorough examination of the subtle aspects that influence user pleasure, trust, and involvement during human-robot interactions. Resolving this gap is critical for driving the growth of intelligent social robots that can positively and seamlessly integrate into human surroundings. Consequently, the purpose of this study is to look into the major obstacles and potential in HCD for HRI, with a particular emphasis on assessing the user experience and accessibility in a variety of interaction contexts.

1.3. Significance of the Study

This study has important implications for the growth of Human-Robot Interaction (HRI), as it provides critical insights into the effective implementation of Human-Centered Design (HCD) concepts. This work adds to the scientific basis of human-robot interaction by rigorously analyzing the experience of users and usability in many scenarios, aiding designers in designing simpler and socially smart robotic systems. The findings of this study have the potential to improve user satisfaction, confidence, and approval, as well as influence the establishment of regulations, standards, and ethical principles for accountable robot design.

2. Theoretical Framework

"Human-Centered Design in Human-Robot Interaction: Evaluating User Experience and Usability" applies major theoretical ideas. At its foundation is the Human-Centered Design (HCD) structure, which incorporates design methodology and user experience design concepts while emphasising the incorporation of human wants and preferences into robotic system development. In addition, the Technology Acceptance Model (TAM) gives an understanding of user attitudes and behavioral intents, directing an investigation of how perceived ease of use and utility influence how people view robotic technology (Akram et al., 2021b). Furthermore, Social Cognitive Theory helps to understand how users create beliefs and gain knowledge from interactions, and Emotional Design Theory exposes the significance of emotions in determining user happiness. The incorporation of Cognitive Load Theory enhances the inquiry into optimising processing of data during human-robot interactions.

2.1. Interaction between Humans and Robots

In this part, we suggest that the manners in which robots incorporate into everyday contexts evoke unique, passionate interaction experiences. Our debate stems from the basic observation that people instinctively treat robots similarly to how they might treat real objects, endowing them with lifelike characteristics such as names, genders, and personalities, even when the robot is not deliberately meant to elicit social responses.

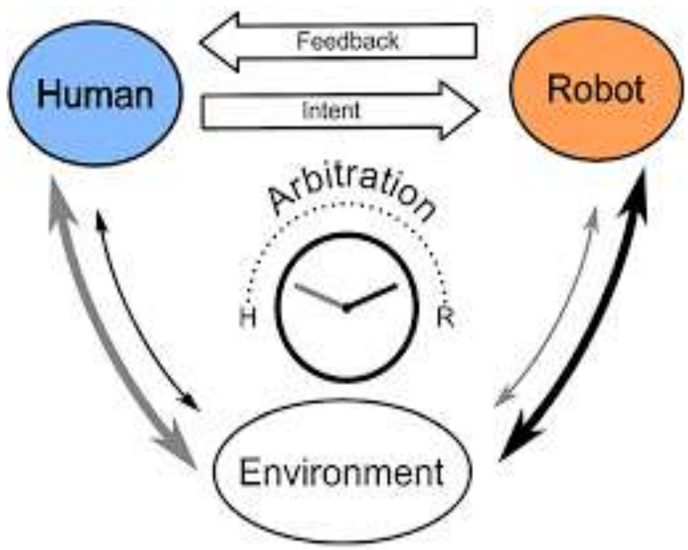

Fig. Human-Robot Interaction with Robust Prediction of Movement

2.2. Robots Enhance Social Interaction

According to studies, humans naturally respond socially and implement social norms to technologies. Since robots are a type of technology, it is reasonable to expect this to occur while engaging with them (e.g., as with humans). Robots have clear physical manifestations, may demonstrate bodily movements, and can interact autonomously within people's environments, distinguishing them from other technology artifacts like a PC or microwaves. Furthermore, the tactile nature of robots, as well as their ability to independently move and act near intimate spaces, is thought to have a distinct impact on social structures and surrounding contact (J. Young, 2011).

Previous research in non-robot interaction between humans and computer scenarios has shown that social proclivities towards technology can be strengthened through the use of socially collaborative technology designs (Al-Adwan et al., 2022). Even for those robots with no intentional social intentions, simple gestures, and skills are frequently interpreted as lifelike, possibly having this effect. As a result, robots that deliberately incorporate modalities such as recognized human-like movements or facial expressions into their designs are likely to entice people to communicate socially with each other in a genuinely unique way (Bartneck C F. J., 2004).

2.3. Anthropomorphism and Agency

People have been shown to anthropomorphize robotics more than other technology, endowing them with characteristics of living beings like animals or other humans. We propose that this embedded anthropomorphism inside physical, and social environments is relevant to how humans readily attach intentionality to robot activities regardless of their real skills or explicit plans. It is our opinion that this intention contributes to and strengthens the robot's sense of agency—the term agency itself implies the ability to act and conveys the idea of intentionality. Many people attach agency to things (for example, "the purposeful position"), We argue that the robot's physical-world integration and socially located context of communication creates a distinctive and affect-charged feeling of engaged agency that resembles that of living entities, such as even basic postures and movements and various technologies (e.g., games with individuals, movies). In some ways, communicating with a robot feels more similar to communicating with a person or an animal rather than technology—the robotic is an engaged social and physical player in our daily routines. People perceive robots to make independent, intelligent choices based on a series of cognitive actions because of agency and intentionality. This viewpoint helps to explain why people frequently assign lifelike traits to robots. (Breazeal, 2003).

Furthermore, the agency helps to the formation of assumptions of the robot's capacities (such as learning ability) or can establish a belief that the robotic will be a proactive social substance all in a much more visible way than more traditional technology. Indeed, it has been established that individuals believe that even basic robots participate in some form of reciprocal social contact and that people acquire deep affective and psychological ties to robots. While individuals can form emotional attachments to inanimate objects (for example, a Tamagotchi doll or an online virtual avatar), robots are unusual in that they can proactively react to people's admiration. Overall, research reveals that robots become active agents in people's settings in the same manner as biological entities do so that these robots naturally blend into social worlds and stimulate emotional participation in ways that more traditional technologies do not (Ana Corrales-Paredes, 2023).

2.4. Physical Interaction Experience

Interaction is present in both our social and physiological realms. Reductive accounts or limited viewpoints cannot fully or effectively understand a person's experience, which includes difficult-to-quantify thoughts, emotions, personal and cultural norms, social structures, and so on. The meaning of experience, from a person's perspective, cannot be separated from the larger, holistic context, which has crucial implications for HRI. (Bartneck C V. M., 2007)

Because of robots' distinctive active agency and realistic presence, this larger context is an important aspect of the interaction experience. The significance of human-robot interaction frequently extends much beyond the simplest point of interaction (specific interface and actions) more profoundly and powerfully than engagement with many older, less active technologies and artifacts, making HRI a very distinct instance of HCI. The robot has a significant impact on the user experience during interaction, which is embedded within a broad context. The robot is a significant and highly engaged social and physiological player in this setting, with an influence similar to that of a biological person in many ways. The human and robot shape the experience in the same way that two living agents do. Our approach here emphasizes the extent to which communication with robots is entrenched in both social and physical environments, as well as the distinctiveness of this integration in comparison to non-robotic HCI examples (such as interacting with a PC). We emphasized the unique aspect of contact with robots in this section. (Breazeal, 2003).

3. Methodology

Human-centered design, according to ISO 9241-210:2019, entails recognizing the requirements of the users, engaging them in the design procedure, and prioritizing the input they provide. To acquire a better knowledge of the existing situation, the current study took an exploratory approach. The information gathered from potential consumers determined the design strategy employed in this study. Participants were recruited using social media channels and the virtual campus. Multiple data sources were employed to collect details about the user experience, including a survey, the robot technician's journals of each session, and video recordings of the sessions**.** The questionnaire was separated into three sections for the participants: contextual information, closed-ended queries, and open-ended questions. Coding and interpretive analysis procedures were used to acquire qualitative data. We employed a mixed-methods strategy to collect data via questionnaires and interviews, as well as to experiment with user interactions. This enabled a more thorough examination of overall performance.

Pepper, a humanoid robot, was used to explore how humans interact with it. It employs head motions, actions, postures, colored eyes, noises, and, in some instances, a dynamic portrayal of emotions via approaches and/or separation from the interlocutor. The robot stands 1.60 meters high, has no feet, and can move its arms, head, and torso. It features sensors and cameras to collect data from its surroundings. The robot's voice is female and easily identifiable from human speech, and the robot's personality is outgoing, taking action and actively interrogating the user. The Robot Training Lab conducted lab-based user research to assess the efficiency of the robot's human-robot communication. Participants were recruited via networking sites, the online campus, and on-campus posters. To preserve their confidentiality and privacy, and to guarantee that the study followed ethical rules, they signed an "Information Sheet and Informed Consent" form. The movies were taken during the sessions to collect gestural data from those using it and to study how they interacted with the robot.

The architecture was deliberately built to assess participants' answers to generate a friendly and non-aggressive relationship between people and Pepper. To build animations and responses for Pepper, we utilized Choreographer edition 2.8.7.4, a robot coding tool that uses the programming languages C++ and Python. The first conversation with those involved always started with a greeting script in which Pepper would say "Hello," ask for the person's name and work, and ask about his/her field of research if the person in question was a student. The conversation changed depending on the participant's responses. Pepper responds to queries by extending its arms, providing various forms of response, and inviting the participant to communicate with it. A table was created to collect details regarding each gesture, such as its particular name and an overview of what it entails to express the emotion with which it is associated.

4. Discussions and Results

Multiple data sources were used to assess participants' reactions to the contact with Pepper, including surveys, open-ended inquiries, photographs, and the programmer's private journal. The data were examined qualitatively in NVivo 13 using coding according to themes and interpretative approaches. After the completion of the training session, attendees were given a computerized questionnaire to fill out, which included three distinct sets of questions. Gender, age, and expertise area were used to filter the questions. The perceptions of users towards the robot were investigated. The findings revealed that users had good opinions of the robot, with younger users perceiving it as a living creature rather than a mechanical **one.** The majority of consumers reported feeling safe and comfortable while engaging with the robot, although others reported feeling tense and uneasy. Even individuals who were stressed or uncomfortable assessed the robot's presence or motions properly or positively.

Several processes were included in the qualitative data evaluation process, including analyzing the written content and recordings of the sessions, setting up the classification dynamics, and debating any variations in the excerpts picked and the categories used. A book of themes was agreed upon and elaborated on during the process. The second stage of analysis employed a logical thematic method to arrange all of the information discovered, and an argument was developed to connect the findings. Users exhibited an interest in the surroundings, including lighting, temperature, and level of noise, which added to a better session. Some people were uneasy about being recorded, but others calmed down during the session. Some people preferred that the robot take their image, while others preferred that they take their own. There are numerous kinds of users' readiness to snap pictures with a robot. A large percentage of users thought it was a positive experience. Users who were unhappy with the robot's continuous hand motions when it was stationary felt uneasy and didn't gain a lot of compassion for the robot. The vocabulary, pronunciation, eye hues, and conversation structure of the robot affected the subjects, prompting feelings of dissatisfaction and estrangement. During the session, participants emphasized the importance of co-interaction and conversation with the robot, and they appreciated how the robot took turns talking and allowed them to talk. Users found Pepper's conversation funny and felt at ease during the interview. Some users were uneasy at times, but the moment Pepper cracked a joke had an advantageous effect on the session. The qualitative results revealed that the human-like features of personality as well as the behavior of social robotics are critical in building a better user experience.

5. Emotional Responses during Human-Robot Interaction

Human-robot interactions (HRI) is a developing field that investigates the complexities of creating robots capable of evoking emotional reactions from users. Studying how emotions function in this situation is critical for developing robots that can integrate effortlessly into a variety of professional and social environments. Research has demonstrated that various design aspects, including as face expressions, speech intonations, and robot body language, significantly add to the psychological reactions of users. (Breazeal C. , 2003) For example, a robot with empathetic expressions on its face can elicit favorable feelings, creating a sense of closeness and rapport. Furthermore, the degree of stereotypes in a robot, or its human-like characteristics, influences emotional responses. Users are more likely to form emotional relationships with robots that have anthropomorphic qualities, highlighting the relevance of design decisions in creating emotional consequences. (Heerink, 2008)

Evaluating feelings during HRI is a complicated difficulty. To analyse user emotions comprehensively, researchers use an amalgam of self-reporting, physiological markers, and observational methodologies. Physiological markers, such as variability in heart rate and skin conductance, provide objective information about users' emotional states. Furthermore, self-reporting methods such as user surveys and interviews provide subjective viewpoints on emotional experiences when interacting with robots. This comprehensive method enables researchers to get a more detailed knowledge of the emotional environment in human-robot interactions (Picard, 1997).

The influence of psychological design on the experience of users is an important part of HRI study. Positive emotional experiences increase user pleasure, engagement, and adoption of robotic systems. Scientists and designers alike hope to employ emotional responses to improve the overall interaction with robots, ultimately aiming to develop socially aware machines that fit smoothly into human contexts. As the subject evolves, further research into emotional reactions in HRI will certainly lead to the creation of robots that not just do jobs efficiently but also engage with users on a deeper level of emotion, revolutionizing how we perceive and communicate with technology (Dautenhahn, 2007).

6. Psychological Factors influencing user perception

Understanding the psychological aspects that influence user perception in the context of interaction between humans and robots (HRI) is critical for developing robotic systems that are compatible with human thought processes and expectations. Customer demands and mental models influence how people perceive and communicate with robots. Users frequently create mental pictures based on their previous experiences, expectations, and ideas about how a robot should act. The variations from these preconceived notions might cause cognitive dissonance and negatively damage user perception. Examining the psychological procedures involved in developing mental models and controlling user expectations is critical when building robots that effortlessly integrate into varied situations and meet human preferences (Hancock, 2011).

In HRI, the concept of cognitive strain and information processing is closely tied to mental models. The cognitive burden imposed on users during encounters with robots has a substantial impact on their capacity to comprehend and effectively engage with the technology. Striking the correct equilibrium between delivering information and preventing information overload is critical. Minimizing cognitive burden through smart design solutions improves user comprehension and satisfaction. Understanding how users absorb information during human-robot interactions is critical for improving the ease of use and enjoyment of automated systems in a wide range of applications (Baxter, 2016).

7. Conclusions, Limitations, and Prospects for Future Research

The study looked at the user experiences when interacting with a robot. It discovered that each scenario had advantages and limitations, as well as lessons keratitis study presents a way for providing social robots with the capacity to sustain an open conversation that is responsive to each user's reactions and moods. This approach relies on modulating conversation profiles. The writers watched all of the videos twice and provided detailed remarks regarding every participant's nonverbal expression. The videos were evaluated using a preset set of criteria. The study discovered that those who participated liked communicating with the robot, finding it novel and entertaining and that older participants, regardless of gender, were more objective in their assessments of the platform. User experience is extremely important in social robots. By taking embodiment into account, robots may grow more approachable, and humans are inclined to relate and feel more at ease during the criteria. The robot activities and answers, based on the study, are critical for promoting seamless and acceptable interaction among humans and robots. Embodied robots can improve learning by making it more engaging and interactive. Our opinions (and the procedures around the experience options map) must be practically and officially deployed in actual assessments to better comprehend the breadth of our proposed methodologies and validate our approach. About this, it's time to provide more concrete techniques and instruments for evaluators to employ when applying perspectives. We anticipate that these will become apparent as we employ the approaches in real-world investigations. Our examination of relevant HCI and HRI assessments described in Sect relied on procedures that we believe are especially pertinent. However, there are many additional techniques that we have yet to investigate, such as research-through-design and video-based evaluations, and it is unclear how our viewpoints will interact with other methodologies.

Robots, by definition, foster social contact and provide humans with a one-of-a-kind interaction experience. The specific mechanics of this phenomenon are unknown, but we believe it is associated with how robots merge into everyday settings, stimulate anthropomorphism, and generate a distinct sense of conscious agency—people naturally perceive robots as if they were living entities. While the domains of HCI and HRI provide numerous well-tested evaluation approaches, we believe there is a vacuum in how these should be used for HRI in a way that recognizes and targets its comprehensive and contextual nature. As a result, we urge academics to investigate this subject further and to develop strategies and methods that specifically target the unique qualities of HRI. We presented a particular strategy in the form of an additional set of viewpoints that assessors can use to help go after the social and context-dependent nature of HRI, emphasized how these viewpoints can be used as a strong vocabulary to debate and identify present work and assessments, and showed how we believe it can be integrated into evaluation in this paper. Overall, we perceive this study as a call to consider the particular issues offered by assessing robots, in addition to a starting step in identifying the problem and suggesting preliminary solutions.

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