Towards a Cultural Perspective on Human-Robot Interaction

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Abstract: Human–robot interaction is a rapidly emerging field whose scope and definition remain diffuse due to its broad application across diverse robotics domains. Research in human–robot interaction typically moves beyond simple input–output interfaces to explore more complex interactions, such as physical collaboration between humans and robots. Consequently, various perspectives on human–robot interaction—ranging from technological considerations and cooperation modalities to trust and safety—have proliferated in both research and practice. Although the priorities in human–robot interaction research often reflect industry demands and societal values, the cultural context in which these priorities evolve has received limited attention. In particular, how different countries' expectations shape the perceived importance of human–robot interaction perspectives remains under-explored. A deeper understanding of these cross-cultural differences can foster a global view of human–robot interaction and support the transfer of best practices across borders. Therefore, this paper examines representative case studies from Germany and India, highlighting key divergences in how human–robot interaction is defined and approached in different cultural and industrial contexts.

1 INTRODUCTION

Human-robot interaction (HRI) is a growing field gaining importance, for instance, in the context of industry 4.0 (Vemuri and Thaneeru, 2023; Daun et al., 2023) or the introduction of advanced service robots in daily life (Fukuda et al., 2011). Thus, research in HRI stems from different robot system types. In addition, the multidisciplinary nature of HRI broadens the field further. From a software engineering perspective, this variety of HRI and the resulting lack of a clear definition, makes it hard to propose development approaches properly considering HRI aspects of robotic software. To help in this, taxonomies and classifications of HRI systems are used to structure the field (e.g., (Onnasch and Roesler, 2021)).

Unfortunately, existing classifications primarily focus on the technical aspects of HRI systems (e.g., (Agah, 2000)), with additional emphasis at times on the social aspects of HRI (e.g., (Gervasi et al., 2020)), or specific factors such as safety (e.g., (Zacharaki et al., 2020; Manjunath et al., 2024)) and security (e.g., (Akalin et al., 2023)). However, all these dimensions are not independent of one-another, and, thus, the interrelations between these are currently not well reflected. For instance, the use of natural language processing approaches for speech recognition (e.g., (Wuth et al., 2021)) is impacted by trust in the company (e.g., (Song and Kim, 2022)).

A challenge in defining a conceptual framework that accounts for the influence of social factors on technological components is the limited understanding of cultural influences. With HRI research being conducted around the world, the approaches are oftentimes not transferable from one country to another due to a difference in social factors rooted in different cultures. For instance, the attitude towards the strictness and importance of safety and security differs between countries (cf. (Weng et al., 2009)). Data protection might be a severe part of cultural life, for example, as shown by the European Union's data protection laws, which limits the use of technology in some countries.

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Therefore, in this paper, we argue that there is a need for a conceptual framework of HRI that not only considers and brings together technological and social factors, but explicitly takes a cultural perspective on HRI into account. Such a conceptual framework on HRI will allow for better classification and comparison of approaches, as well as supporting transferability of approaches from one country's cultural background to another. In this paper, we exemplarily investigate the need for a conceptual framework considering case examples from Germany and India. In doing so, we show the need to a) consider a cultural perspective for HRI, and b) consider the influence of culture on the interrelation between social factors and technological components of HRI.

The paper is outlined as follows: Section 2 introduces HRI and reviews existing taxonomies and research related to culture in HRI. Section 3 presents the initial conceptual framework for HRI, differentiating between technical, social, and cultural perspectives and their interrelations. Section 4 discusses a case study from Germany and India. Finally, Section 5 concludes the paper.

2 RELATED WORK

2.1 Culture in HRI Research

The concept of culture has been extensively studied across disciplines, with each focusing on different aspects such as shared customs, rules, attitudes, and social practices (Koltko-Rivera, 2004). It encompasses diverse elements, including traditions, technologies, and collective behaviors (Matsumoto and Juang, 1996). In computing, culture concerns enabling users to engage through the values and characteristics of their cultural identity (Rauterberg, 2006).

Cultural values influence not only the development of robots, but also the reciprocal impact of robotic cultural values on human behavior (Samani et al., 2013), further contributing to trust and trustworthiness in HRI. Cultural studies also contribute to ensuring effective and meaningful interactions between humans and robots (Keay, 2012). A study by Evers et al. (Evers et al., 2008) examined how cultural frameworks shape user behavior in HRI by comparing relational and group self-construal, highlighting the influence of culture and background on these interactions. Building on this, Salem et al. (Salem et al., 2014) explored politeness, showing that user perceptions of robots are influenced by social norms and expectations. Additionally, cultural norms impact user comfort levels regarding proxemics, or the spatial behavior of robots (Joosse et al., 2014).

Social robots are designed to interact with people in a natural, interpersonal manner, unlike robots in industries where their actions are predetermined, and the environment is controlled. Social robots are meant to achieve positive outcomes in diverse applications such as education, health, quality of life, entertainment, communication, and tasks requiring collaborative teamwork (Breazeal et al., 2016). These applications contain global implications and in order to enhance its global adoption, these robots should be culturally competent (Lim et al., 2021). A case study by Bennett et al. (Bennett et al., 2022) compares the use of robotic companion pets in South Korea and the United States, highlighting divergent cultural attitudes toward robot anthropomorphization and utility. Robots can also represent cultural emotions and thus provide a framework for embedding culturally specific cues in robot designs (Dang et al., 2017). This aligns with broader discussions on the ethical and conceptual fragmentation of cultural robotics (Mansouri and Taylor, 2024; Bruno et al., 2017).

In the context of WEIRD (Western, Educated, Industrialized, Rich, and Democratic) societies, HRI still lacks diversity (Seaborn et al., 2023). Cultural contexts play a crucial role, as they vary significantly across different cultures and must be studied to promote inclusivity. A dynamic and adaptable HRI system that incorporates user-specific cultural traits can enable the development of culturally competent robots (Bruno et al., 2017). Additionally, social psychological theories provide a theoretical foundation for understanding the cultural dimensions of human-robot relationships (Smith et al., 2021).

These studies highlight the importance of culture in shaping robotic behavior and interaction channels to align with user expectations. Therefore, they can be taken to advocate the need for a cultural dimension in HRI research. However, these studies only investigate the influence of culture on direct interaction between human and robot. In contrast to our approach, they do not consider cultural attitudes towards the use of technological components of HRI. Thereby, we aim at explaining country-specific differences in HRI research which allows for comparability and transferability of HRI research between different cultural contexts.

2.2 Existing Classifications

Based on the nature of the work performed, the type of contact, and the restrictions of the workspace, HRI can be categorized into different types. Referring to Bauer et al.'s (Bauer et al., 2016) categorization of interaction types—which is widely used in the field and covers numerous modalities—these types include Human-Robot Cell, Human-Robot Co-existence, Human-Robot Synchronization, Human-Robot Cooperation, and Human-Robot Collaboration. These types differ based on varying degrees of autonomy, which influence the dependencies between humans and robots (Jesus Raja et al., 2024).

In (Onnasch and Roesler, 2021), a taxonomy for structuring and analyzing HRI was proposed which contains emphasizing factors such as interaction modalities, levels of autonomy, and user roles. This taxonomy addresses the varying degrees to which humans and robots can collaborate—ranging from simple, sequential interactions to highly interdependent, synchronized tasks. The taxonomy categorizes HRI into three main types: Classification of interaction, Classification of robot and Classification of the team.

Gervasi et al. (Gervasi et al., 2020) proposed a conceptual framework to evaluate human-robot collaboration, comprising eight latent dimensions: autonomy, information exchange, team organization, adaptivity and training, task, human factors, ethics, and cybersecurity. Within this framework, human factors include elements such as workload, trust, robot morphology, physical ergonomics, and usability, while ethics encompasses aspects like social impact and social acceptance. Notably, culture is not explicitly included as a dimension, despite its influence on factors such as social acceptance, trust, and social impact. This omission highlights a gap in addressing cultural considerations.

3 CONCEPTUAL FRAMEWORK

The currently existing classifications in HRI primarily consist of technical factors, such as degrees of autonomy, sensing capabilities, and human-machine interface designs, and, to some extent, social aspects, such as trust and acceptance. The incorporation of cultural aspects, which influence the social aspects, is still lacking. Therefore, we propose a conceptual framework explaining the influence of cultural aspects on social and technical dimensions of HRI. Figure 1 illustrates the three perspectives, along with examples and their interrelationships.

3.1 Technical Perspective

In the field of HRI, the technical perspective represents the infrastructure that allows interaction between humans and robotic systems. This perspective encompasses the essential hardware and software components, ranging from sensing mechanisms to advanced computational architectures, that collectively facilitate robot functionality. By examining these technical elements, we can better understand what components are required for the development of the robotic system and how and why these components are influenced by social and cultural aspects. For instance, in collaborative manufacturing environments, the integration of advanced perception systems with precise motion control algorithms enables robots to work safely alongside human operators while maintaining optimal performance. In Figure 1, the block labeled ① provides a list of aspects from the technical perspective, for example:

- **Sensing Mechanisms:** These include environmental sensors, cameras, and detection systems that allow robots to perceive and understand their surroundings, enabling safe and effective interaction with humans.
- **Actuation Systems:** Components that enable robots to interact with their environment by converting energy into motion. This conversion process allows robots to perform tasks ranging from simple to complex. Actuators are the driving force behind a robot's ability to move.
- **Computational Processing Units:** High-performance computing architectures handle complex calculations and real-time decision-making processes when the robot works.
- **Interface Modalities:** Robots communicate with humans through various channels including touchscreens, voice commands, and gesture recognition systems. These different interaction methods ensure that humans can communicate naturally and effectively with robotic systems.
- **Motion Control Algorithms:** The smooth and precise movements of robots are guided through preplanned and executed trajectories. These algorithms ensure robots move safely around humans while efficiently completing their tasks.
- **Perception Systems:** Advanced software that processes the data from various sensors to help robots understand their environment. This includes recognizing objects, tracking human movements, and understanding spatial relationships in the workspace.
- **Human-Machine Interfaces:** The points of interaction between humans and robots are designed to be intuitive and user-friendly. These interfaces allow operators to communicate their intentions and understand robot status easily.
- **Communication Protocols:** Various components of a robotic system exchange information through

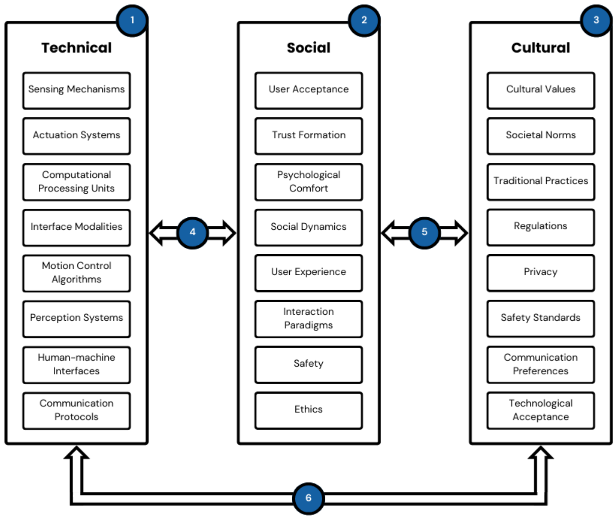

Figure 1: Conceptual HRI Framework Differentiating between Three Major Perspectives and Their Interrelations.

standardized methods. These protocols ensure reliable and efficient data flow, enabling coordinated operation of all system parts.

3.2 Social Perspective

HRI fundamentally relies on understanding and addressing social dynamics between users and robotic systems. For instance, in healthcare, robots must establish trust and maintain user comfort while performing tasks. The social perspective (labeled ② in Figure 1) examines how humans perceive and respond to robotic interactions, considering factors from initial acceptance to long-term collaboration patterns. Important aspects of the social perspective contain:

- **User Acceptance:** This aspect tells how different users adapt to and accept robotic systems, and how this varies based on their experience and context. For instance, healthcare workers may readily accept assistive robots when they clearly understand the benefits and receive proper training.
- **Trust Formation:** Building trust between humans and robots happens through consistent and transparent robot behavior. When robots communicate their intentions clearly and perform reliably, users develop confidence in working alongside them.
- **Psychological Comfort:** The level of comfort humans feel around robots depends on factors like robot movement, speed, proximity, and predictability. Careful consideration of these elements ensures positively perceived HRIs.
- **Social Dynamics:** The way humans and robots interact creates unique social patterns that evolve over time. Understanding these dynamics helps in designing more effective collaborative scenarios.
- **User Experience:** The overall interaction experience must be intuitive and satisfying for different user groups. This includes various factors from interface design to robot responsiveness.
- **Interaction Paradigms:** This aspect tells us how robots behave in different social situations. This includes determining when robots should be proactive versus passive in their interactions.
- **Safety:** Beyond physical safety, ensuring that users feel psychologically secure working with robots is crucial. This encompasses both actual and perceived safety measures.
- **Ethics:** Robots must operate within clear ethical guidelines that respect human values and rights. This includes considerations of privacy, autonomy, and fair treatment.

3.3 Cultural Perspective

The technical perspective represents the physical infrastructure enabling interaction between humans and robotic systems, while the social perspective addresses the dynamics of these interactions. The cultural perspective (labeled ③ in Figure 1) influences both the technical and social aspects. This influence on the technical aspects shapes the refinement of technical components that constitutes a robotic system. It highlights how cultural factors impact robot design, behavior, and acceptance across different contexts and regions. Important cultural aspects include:

- **Cultural Values:** Different societies hold varying beliefs about automation and HRI.

- **Societal Norms:** Acceptable robot behavior varies across cultures, from communication styles to physical proximity.
- **Traditional Practices:** Considering local customs and traditions can make robots user-friendly, gaining user acceptance. For example, greeting the human while passing by can have a positive impact on the human.
- **Regulations:** Different regions have varying legal requirements for robot deployment. These regulations shape technical implementations and operational parameters.
- **Privacy Expectations:** Cultural attitudes toward privacy affect how robots should handle personal information and maintain appropriate boundaries.
- **Safety Standards:** Regional differences in safety expectations require adaptable robot behavior and safety protocols.
- **Communication Preferences:** The way robots communicate must align with local customs and preferences, from language use to non-verbal cues. For example, colors differ based on cultural preferences or professional rules.
- **Technological Acceptance:** Different cultures show varying levels of openness to robotic technologies, affecting implementation strategies.

3.4 Technical-Social Interrelations

The interrelation between technical capabilities and social requirements (labeled ④ in Figure 1) creates crucial relationships that shape effective HRI implementation. For instance, in collaborative manufacturing or healthcare robotics, we observe how technical features must adapt to social needs, ensuring both functional efficiency and user acceptance. The following aspects highlight key areas where technical and social interdependencies shape robot design and functionality:

- **Interaction Modalities:** The way technical interfaces adapt to different user preferences impacts acceptance and usability. For example, elderly users might prefer simple voice commands, while industrial workers may favor touchscreen interfaces for precise control.
- **Robot Behaviors:** The technical implementation of motion control systems must consider social factors like user comfort and safety. This includes the robot adjusting its speed and maintaining appropriate distances to humans.
- **Communication Protocols:** Technical feedback systems influence trust development through clear and consistent communication. Robots signaling their next actions through visual or auditory cues help users understand and predict robot behavior.
- **Motion Planning Systems:** How robots move aligns with human psychological comfort. This includes smooth trajectory adjustments when approaching humans and predictable movement patterns in shared spaces. Additionally, user comfort and safety concerns also influence the way motion control systems are implemented.

3.5 Cultural-Social Interrelations

The relationship between social interaction patterns and cultural norms (labeled ⑤ in Figure 1) influences how robots should behave in different societies. Understanding these connections is crucial for developing robots that can operate effectively across diverse cultural contexts. The following aspects highlight key areas where cultural and social interdependencies shape robot design and functionality:

- **Cultural Attitudes:** Social acceptance of robots varies significantly across cultures, affecting how users prefer to interact with them. Some societies readily accept robots in care roles, while others prefer limiting them to industrial applications.
- **Risk Protocols:** Safety measures must align with cultural risk tolerance levels. This includes adapting robot behavior and safety protocols to match local expectations and norms.
- **Social Interaction Designs:** Robot interaction patterns need to reflect local communication styles and customs. This affects, e.g., personal space maintenance or communication timings.
- **Privacy Mechanisms:** Trust-building approaches must consider cultural privacy expectations. This influences how robots collect, handle, and communicate about user data.

3.6 Cultural-Technical Interrelations

The influence of cultural requirements on technical implementations (⑥ in Figure 1) shapes how robotic systems are developed and deployed across different regions. This relationship ensures that technical solutions remain culturally appropriate and effective. The following aspects highlight key areas where technical and cultural interdependencies shape robot design and functionality:

- **Regulations:** Technical control systems must adapt to meet varying geographical safety and operational requirements. This includes different safety protocols, standards, and certification.

- **Data Protocols:** Robots should process and store information to align with local privacy standards and cultural expectations about data handling.
- **Natural Language Processing Systems:** Language processing capabilities must account for cultural communication patterns, including formal versus informal speech and non-verbal cues.
- **Cultural Contexts:** Technical development priorities should reflect local values and needs, ensuring that robot capabilities align with cultural expectations and practices.

4 CASE EXAMPLE

The HRI assembly process used is a sorting process performed collaboratively by humans and robots, involving tasks such as categorizing, scanning, and transporting. The cobot picks and places packages, scans barcodes, and transports them to the designated zone. Humans handle irregularly shaped packages and resolve ambiguities, such as categorizing new or unidentifiable items. The cobot operates in close proximity to humans while adhering to strict safety protocols to ensure smooth interaction. Figure 2 shows the technical, the social and cultural aspects for India and Germany respectively. The figure shows how the aspects differ significantly between the two countries.

For example, in Germany, the technical aspect of “advanced sensors and high-precision equipment” is supported by the social aspect of a “technology-first mindset,” which reflects how Germans prioritize innovation and quality. This social factor is further influenced by the cultural emphasis on “precision and efficiency,” a value that strongly shapes the work culture of Germany. In contrast, in India, the technical implementation of “semi-automated flexible systems” is shaped by the social focus on “collaborative, community-based dynamics,” which stems from the cultural emphasis on “community and adaptability.” India, being a labor-intensive country, necessitates having a semi-automated system rather than a completely automated one, allowing robots to work alongside humans.

This systematic progression from cultural to social to technical aspects is evident in many scenarios illustrated in Figure 2. For instance, standardized interfaces and fully automated systems align with Germany’s social emphasis on efficiency-focused user experience and certification-based trust formation is rooted in process-oriented cultural norms. Similarly, the Indian approach of employing user-friendly interfaces and balanced automation with manual override capabilities highlights how Indian manufacturing prioritizes workforce diversity while embracing technological advancement.

However, the influence of culture on technical aspects does not always pass through social factors and can directly shape technical implementations. For example, in German manufacturing, the cultural foundation of “process-oriented work culture” and “comprehensive guidelines” directly shapes the technical aspect of “highly structured, well-documented systems.” In the Indian context, the cultural aspect of “flexible work approaches” directly impacts technical solutions, resulting in “simple, user-friendly interfaces.” This cultural-technical relationship is further exemplified by the cultural emphasis on blending modern and traditional methods, which translates into adaptable, multilingual support systems to accommodate the diverse languages and cultures of each Indian state, as well as balanced automation solutions. These examples demonstrate how cultural values such as workforce diversity and adaptability directly shape technical implementations in Indian manufacturing settings.

The interdependencies shown for both Germany and India are not one-to-one; a single cultural aspect can influence multiple technical aspects, and a single technical aspect can also be shaped by multiple cultural factors. These examples highlight how cultural differences, which are contrasting in nature for both countries, shape perceptions and priorities, thereby influencing both social dynamics and technical implementations. While Germany and India differ in social aspects, these differences stem from their distinct cultural foundations.

Robots in India are often designed to assist humans in manual tasks rather than replace them entirely (Goodrich et al., 2008). Regarding cultural acceptance, perspectives in India vary based on socioeconomic factors and exposure to technology. Urban populations generally have welcoming and integrative views towards robots, while rural communities exhibit more diverse perceptions (Deshmukh et al., 2018). For the Indian market, addressing societal concerns such as job displacement is critical. Robots in India are designed to complement human labor, which has fostered acceptance across diverse communities (Haring et al., 2019). This emphasizes the profound impact of cultural factors on the social and technical dimensions of HRI. In contrast, Robots in Germany are predominantly designed to meet high-quality standards, adhering to the country’s rigorous safety norms. In industrial settings, the focus is on achieving precision and maximizing production with minimal human involvement.

Category	Indian Perspective	German Perspective
Technical		
Sensing Mechanisms	Cost-effective, adaptable solutions	Advanced sensors, high precision equipment
Actuation Systems	Semi-automated, flexible systems	Fully automated, high-end systems
Interface Modalities	Simple, user-friendly interfaces	Standardized interfaces
Motion Control	Balanced automation with manual override	Precise, safety-first algorithms
Communication Protocols	Adaptable, multilingual support	Highly structured, documented
Social		
User Acceptance	Progressive adoption with human focus	Technology-first mindset
Trust Formation	Built through personal interactions	Based on certification and standards
Social Dynamics	Collaborative, community-based	Formal workplace interactions
User Experience	Emphasis on ease of use	Efficiency-focused
Safety	Balanced with productivity	Primary concern, strict protocols
Ethics	Focus on job preservation	Strong emphasis on data protection
Cultural		
Cultural Values	Community and adaptability	Precision and efficiency
Societal Norms	Flexible work approaches	Process-oriented work culture
Traditional Practices	Mix of modern and conventional methods	Structured workflows
Regulations	Adaptive regulatory frameworks	Strict compliance requirements
Safety Standards	Contextual safety protocols	Comprehensive guidelines
Technological Acceptance	Growing acceptance with focus on human-robot collaboration	High adoption readiness

Figure 2: Conceptual HRI Framework: Comparative Overview of Indian and German Perspectives.

5 CONCLUSION

HRI continues to evolve as a multidisciplinary field, providing innovative solutions to complex tasks that require collaboration between humans and robots. While HRI has seen significant research, especially for the technical and social aspects, the influence of cultural aspects still remains under-explored. This paper addressed this gap by examining the cultural, social, and technical interdependencies in HRI through a comparative case study of Germany and India.

The findings reveal that cultural values play a pivotal role in shaping key aspects of HRI, including safety mechanisms, communication styles, and system adaptability. In Germany, HRI systems emphasize precision, compliance, and strict safety protocols, reflecting cultural priorities rooted in structure and standardization. In contrast, Indian systems prioritize cost-effectiveness and collaborative human-robot dynamics, driven by cultural values of flexibility and inclusivity. These insights underscore the importance of integrating cultural considerations into HRI design to enhance adaptability and effectiveness in diverse environments. By embedding cultural awareness during the early stages of system development, researchers and practitioners can account for the varying needs, preferences, and constraints of different societies. For instance, integrating culturally tailored safety protocols can enhance user trust and acceptance, while designing adaptable communication systems ensures that robots interact effectively across linguistic and social boundaries. Moreover, culturally aware HRI frameworks can better address ethical concerns, such as privacy and job displacement, by aligning robot behavior with local societal norms. Such considerations are crucial for fostering meaningful and sustainable human-robot collaborations in global contexts.

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