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Integrating World Views: An Early Step Towards Human-Robot Cooperation in Tomorrow's Manufacturing Facilities

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Abstract

This HRI (Human Robot Interaction) evaluation examines how people regard robots across multiple parameters. Current methods for evaluating views rarely disclose the complex psychological aspects at play. Merging the results of three investigations and basing it on a comprehensive framework that integrates several psychological theories, including de-humanization theory, would provide a better questionnaire. The scale designed for this research measures sociability, agency, animativity, and disturbance. By studying these sub-factors, we can better understand how they may affect future robot attitudes. As corporations automate and adapt, robots that can flourish in changing environments, especially those they share with people, are in demand. This research identifies the finest sensory equipment for detecting individuals and their actions in production. This paper examines fixed-base manipulators, collaborative robotics, mobile robots, and mobile manipulators. It details sensors and methods that improve human perception. The study also shows two proof-of-concept ways to improve industrial human-robot collaboration and safety. This study examines how cultural influences affect people's perceptions and responses to social robots in service and social contexts. Twenty years of HRI data show the complex interaction between cultural setting and cognition. This study examines how national identity and robot experience impact viewpoints across Eastern and Western cultures. It also demonstrates how much more work is needed to standardize methodologies and raise statistical power in future studies to improve transferability. The study emphasizes the importance of cultural elements in robot design to promote human-robot interaction.

Keywords: HRI; Fixed-Base Manipulators; Mobile Robots; Mobile Manipulators; Cultural Elements

Abbreviations: CPHSs: Cyber Physical Human Systems; HRI: Human Robot Interaction; FoF: Factory of the Future; HR: Human Robot; LIDAR: Light Detection and Ranging; HRC: Human Robot Collaboration; HHIs: Human-Human Interactions; CPS: Cyber-Physical Systems; IMRs: Intelligent Mobile Robots; CPS: Cyber-Physical Systems; AMRs: Autonomous Mobile Robots; HRP: Human-Robot Perception; AGVs: Automated Guided Vehicles; AMRs: Autonomous Mobile Robots; IMRs: Intelligent Mobile Robots; CNNs: Convolutional Neural Networks; HRC: Human-Robot Collaboration; ROPA: Robot Perceptual Adaptation; RNNs: Recurrent Neural Networks; SAN: Social-Aware Navigation; SAR: Spatial Augmented Reality; AR: Augmented Reality

Introduction

The function of robots in the dynamic domain of smart factories and manufacturing has gained significant importance, signifying a fundamental transformation in the execution of production processes. The emergence of Cyber Physical Human Systems (CPHSs) is driven by a specific emphasis on fostering collaborative environments between human employees and robots. This concept challenges conventional notions that view people as disruptors inside automated processes. The advancement of technology in the Factory of the Future (FoF) requires improved perception capabilities of Human Robot (HR) systems in order to facilitate smooth and efficient Human Robot Interaction (HRI) [1-3]. The incorporation of sensors into the production system is crucial for the attainment of effective Human-Robot Interaction (HRI), as robots must be able to perceive and engage with human operators within a collaborative workplace. The sensors mentioned in this statement consist of a range of technologies, which include vision sensors such as monocular RGB, stereo, RGB-D, and event-based cameras. Additionally, distance sensors like LIDAR are also included in this category. The sensors possess the capability to not only identify and mitigate noise in data, but also engage in information processing via edge computing. This functionality is particularly significant in the context of a digitalized manufacturing environment, as it enables predictive maintenance operations [4].

Human Robot Collaboration (HRC) in the industrial context is distinguished by three distinct stages, namely Coexistence, Cooperation, and Collaboration. The levels in question delineate the manner in which human beings and robots engage with one another in a collaborative work environment, necessitating certain safety protocols as stipulated by ISO/TS 15066. Ensuring safety is of utmost importance in facilitating the incorporation of these technologies, as the absence of adequate safety measures might result in occupational harm, particularly due to the robots' low situational awareness. The proliferation of robotics in various societal domains necessitates an examination of the cultural factors that shape human attitudes and engagements with social robots. The significance of social presence in robotics is increasingly recognized as the field expands beyond its industrial roots. This recognition is driven by the emotional expressions exhibited by robots and their capacity to elicit social responses. The investigation of emotions during Human- Robot Interaction (HRI) has been prompted, leading to the emergence of a multidisciplinary area encompassing robotics, engineering, computer science, cognitive science, and psychology. The role of emotional signals is crucial in influencing the sense of transparency in Human-Robot Interaction (HRI), hence improving the quality of social interactions with robots [1, 3, 5, 6].

Nevertheless, the introduction of socially supportive robots prompts inquiries regarding the influence of culture on the dynamics of human-robot interactions. The impact of cultural differences on attitudes and behaviors towards robots has been acknowledged, although it is difficult to measure and quantify. The inclusion of cultural factors within the examination of Human-Robot Interaction (HRI) enhances our comprehension of intricate concepts, such as empathy, perspective-taking, and self-other understanding. By combining theories of culture with empirical research, a deeper understanding of the intricate impact of culture on Human-Robot Interactions (HRIs) may be achieved. This knowledge can then be utilized to develop design principles for robots that are more inclusive and sensitive to the specific cultural contexts in which they operate [7-11].

This review paper explores the interconnectedness of technology, human psychology, culture, and robots. The Factory of the Future is being shaped by the emergence of smart manufacturing and the integration of robots into numerous societal domains. This development highlights the importance of seamless collaboration between humans and robots, as it encompasses crucial aspects such as safety, perception, interaction, and culture. By conducting a comprehensive examination of these dimensions, our aim is to elucidate the nascent patterns and obstacles that facilitate the advent of a novel epoch characterized by the symbiotic relationship and cooperation between humans and robots.

Literature Review

Bonci et al. explore the crucial significance of perceptual capacity in the context of human-robot interaction in industrial settings. The growing necessity for achieving high levels of automation in order to effectively respond to quickly changing market requirements underscores the critical importance of robots' adaptability and flexibility. Autonomous and collaborative robots, possessing the ability to adaptively react to diverse environmental circumstances including the presence of humans, are identified as key participants within this domain. Nevertheless, the absence of the capacity to discern human position and purpose in shared workstations could potentially undermine both productivity and safety. This extensive examination examines the sensory equipment that is crucial for the detection of humans and the recognition of their actions in industrial environments. This study offers a comprehensive analysis of various sensors and perception methodologies. Furthermore, the evaluation spans a range of robotic systems frequently employed in industrial settings, including fixed-base manipulators, collaborative robots, mobile robots, and mobile manipulators. This study examines the optimal sensors and approaches utilized in cooperative and collaborative industrial applications for the purpose of perceiving and responding to human operators. In addition, the paper presents two persuasive demonstrations created by the authors as evidence of their efforts to improve the collaboration capacities of robots in terms of human perception and interaction. The first concept pertains to the aspect of ensuring human safety in jobs that involve collision avoidance and the identification of moving obstacles for collaborative robots with fixed bases. The second notion elucidates a collaborative behavior that can be used to autonomous mobile robots engaged in assigned tasks inside shared industrial environments in conjunction with human operators (Bonci et al.) [12].

Turn-taking, an essential component of human discourse, encompasses the synchronization of speaking and listening during conversational interactions. While humans demonstrate seamless turn-taking with minimal gaps and overlap, conversational technologies such as voice assistants and social robots frequently encounter challenges in effectively managing interruptions and response delays. This review paper examines the substantial amount of research that has been conducted to improve the process of turn-taking in conversational systems. Skantze [13] conducted a comprehensive analysis of a review, which commences by building a theoretical framework and digging into the linguistic study tradition pertaining to turn-taking, as well as exploring essential notions within this particular subject. The subsequent analysis offers a comprehensive exploration of multi-modal cues, including verbal cues, prosody, breathing, gaze, and gestures. These cues have demonstrated their efficacy in promoting coordination of turn-taking in human-human interactions and can be modified for application in conversational systems. The subsequent section of the study explores the process of modeling turn-taking, with a particular focus on key elements such the detection of the end of a turn, the management of user interruptions, the generation of turn-taking cues, and the facilitation of interactions involving many participants in human-robot interactions.

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This review seeks to offer a complete overview of the present state of turn-taking in conversational systems by synthesizing existing research. In summary, this work highlights the crucial areas that require additional investigation in order to achieve smooth turn-taking in spoken interactions between humans and machines. It provides essential guidance for future research endeavors in this particular domain. In the area of service, recent technological breakthroughs have brought forth a notable age characterized by the ability of robots to exhibit emotions. Nevertheless, the understanding of emotions in the context of human-robot interaction is still an area that has not been well explored. This evaluation investigated by Yu and his team centers on emotions, renowned for their ability to spread, and employs Instagram data to reveal the influence of emotional robots on the affective experiences of potential buyers. By utilizing machine learning algorithms and conducting sentiment analysis, our research highlights the importance of surprise and joyful expressions in eliciting favorable outcomes among potential consumers. This interdisciplinary inquiry not only illuminates the underexplored aspects of emotion in robotics but also establishes a foundation for forthcoming investigations in the fields of social, design, and creative encounters within the domain of artificial intelligence in consumer service and experience settings (Yu et al.,) [14].

The efficiency and productivity of smart manufacturing and smart factories are heavily dependent on the utilization of automation and robotics, whereby human- robot collaboration (HRC) assumes a crucial function. Nevertheless, the incorporation of industrial robots into human-robot collaboration (HRC) environments poses safety concerns that necessitate meticulous consideration. This review paper investigates the different degrees of collaboration within the field of human-robot collaboration (HRC) and analyses the safety measures implemented to avoid potential dangers. A thorough examination of available literature identified a total of 193 papers that were deemed relevant. These articles were then subjected to a screening process and eligibility assessments, ultimately leading to the selection of 46 publications for the purpose of extracting data. The study involved the extraction and analysis of key factors utilized in Human-Robot Collaboration (HRC), including devices, algorithms, collaboration levels, safety measures, and standards. Remarkably, the results of our investigation demonstrated by Arents and her coworkers that, while the intimate collaboration between people and robots, a significant proportion of the examined research, specifically 25%, did not incorporate any safety measures, while more than 50% failed to comply with recognized safety protocols. This research aims to examine the dominant patterns observed in Human Rights Council (HRC) practices and emphasize the shortcomings present in existing HRC systems. This research underscores the importance of addressing safety procedures throughout the early stages of HRC system development in order to guarantee the secure and efficient operation of smart manufacturing environments, given the inherent complexity of these systems (Arents et al.)[15].

Exploring the Convergence of Culture and Robotics through a Sociological Lens

Previous studies conducted on Human-Robot Interactions (HRIs) have revealed that individuals' interactions with robots are influenced by their prior experiences and expectations, which closely resemble the patterns observed in human-human interactions (HHIs) [16]. Therefore, it is logical to deduce that our interactions with robots have the potential to shape our future engagements with these independent entities. This section aims to investigate the potential impact of an individual's cultural affiliation and identity on the process under consideration. It will delve into the existing body of research to provide a comprehensive understanding of how and to what extent cultural background influences emotions, cognitive processes, and perceptions of robots in the context of human-robot interaction (HRI). Although a comprehensive analysis of the beginnings of culture is outside the purview of this paper, contemporary scholarly works have engaged with the importance of culture and philosophy within the realm of Human-Robot Interaction (HRI) [17,18]. Within the realm of philosophical frameworks, Western traditions, which span Europe and the Americas, are contrasted with Eastern philosophies, exemplified by places such as Asia and the Middle East. The Western intellectual tradition has a tendency to pursue systematic, coherent, and all-encompassing interpretations of the cosmos, even in the face of substantial changes in the conception of human life. This is done in order to integrate novel concepts with the maintenance of existing systems of thought, as exemplified by Freud's exploration of the unconscious mind. In contrast, Eastern philosophical traditions have exhibited a historically consistent trajectory. In the context of Japan, there is a prevalent inclination towards animism, which encompasses the Buddhist notion that all entities, regardless of their vitality, are inhabited by souls. There are proponents who believe that these cultural and philosophical tendencies could potentially cultivate a heightened level of acceptance towards robots within the Japanese society [19]. In the present-day context, the phenomenon of globalization has facilitated the swift spread of information and fostered heightened cross-cultural connections. Therefore, it can be argued that conventional values, as previously mentioned, might not possess the same degree of impact, particularly in specific cultural environments. However, the enduring presence of values that are firmly ingrained in our cultural past continues to complicate the field of cultural studies, especially when investigating the impact of culture on Human-Robot Interaction (HRI), which encompasses a complex network of interconnected concepts.

The Intersection of Robotic Systems and Human-Robot Perception

This section examines various types of robotic systems that are frequently employed in industrial settings, namely fixed-base

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manipulators, cobots, mobile robots, and mobile manipulators. The objective is to demonstrate how these systems perceive and respond to the presence of human operators or stationary obstacles in industrial scenarios, particularly in cooperative and collaborative applications. The section concludes with a comprehensive discussion of the most often utilized sensors and HRP (Human-Robot Interaction) approaches.

Fixed-Base Manipulators and Collaborative Robots (Cobots)

In this section, we will discuss the concepts of fixed-base manipulators and collaborative robots, commonly referred to as Cobots. The field of Human-Robot Collaboration (HRC) in the context of fixed-base robotics has become a central area of focus in recent research efforts [20-22]. In instances when people and robots coexist in the same workspace, there are two separate situations that require careful consideration:

i. The concept of "full awareness" refers to a state of complete consciousness and mindfulness. In this particular setting, it is crucial to uphold a thorough understanding of the presence of human beings and the surrounding ecological factors. The accomplishment of this objective involves the utilization of a diverse set of sensors for the purpose of monitoring human presence and impediments inside the operational area of the manipulator. This process facilitates the creation of a comprehensive three-dimensional representation of the surrounding environment. This complete comprehension enables continuous monitoring of the spatial separation between the robot and various objects inside the designated operational area. Subsequently, a controller operating at a higher level possesses the capability to modify the trajectory of the robot, thereby proactively preventing collisions or ceasing operations as deemed necessary [23-25].

ii. Management of Safe Spaces: On the other hand, there are some situations where the primary objective is to guarantee the secure handling of communal areas in order to mitigate potential risks to individuals caused by the movement of robots. In instances of this nature, the identification of collisions is commonly achieved using the estimation of the robot's dynamic characteristics, in combination with data obtained from proprioceptive sensors that are typically an integral part of industrial robots. The motion of the robot is subsequently re-planned and regulated in order to reduce contact forces, thus ensuring that possible collisions with humans or barriers do not pose a threat [26].

This section examines the latest advancements in human resources (HR) applications, specifically emphasizing the use of exteroceptive sensors. It also acknowledges the existence of proprioceptive-based approaches for predicting robot contact forces, which rely on knowledge of robot dynamics. In the absence of exteroceptive sensors, robots experience a deficiency in perceiving the three-dimensional external environment [27]. Consequently, they rely on controlled interaction forces to ensure safety, but this approach renders the robot unaware of the presence of humans and barriers. Currently, in the field of commercial cobots, there is a prevailing utilization of approaches that impose limitations on pressures and avoid reliance on vision sensors. Cobots, which are distinguished by their sleek exteriors and appropriate operational speeds for human collaboration, demonstrate efficient functionality through a limited knowledge of potential contacts rather than a comprehensive perception of their surroundings [28].

In accordance with the requirements outlined in ISO/TS 15066:2016, there have been recent endeavors to enhance the capacity of conventional manipulators to engage in collaborative tasks alongside human counterparts. One approach, for example, involves constraining forces exerted by conventional industrial manipulators and detecting collisions without the need for external sensors. The methodology utilized in this study involves the utilization of time-invariant dynamic models and supervised feed-forward input-delay neural networks in order to accurately estimate the necessary current signals for a specific robot motion. Collision detection is observed when the measured motor currents exceed the anticipated values [29, 30]. An alternative methodology circumvents the use of external force sensors by using the robot's dynamic model, which may be applied in both dynamic and quasi-static scenarios, for the purpose of detecting external forces.

In order to tackle the existing constraints in HR applications, namely those that heavily rely on exteroceptive sensors such as vision sensors, this section delves into potential remedies, despite the presence of obstacles pertaining to precision and consistency. Vision sensors possess a heightened susceptibility to external variables such as illumination levels and reflectance. Nonetheless, they provide robots with a holistic perception of their environment, facilitating the avoidance of obstacles and the adjustment of trajectory. Various types of vision systems commonly used in HR collaborative applications include stereo cameras, RGB-D cameras (which combine color and depth information), proximity sensors, and laser scanners. These sensors enable the tracking of obstacles, offer insights into human intents, and produce three-dimensional models of the environment, among other capabilities [31-33].

This section of the paper examines the present condition of exteroceptive sensors in applications related to heart rate (HR), with a specific focus on three key factors: the specific type of sensor utilized, the methodology employed for detecting obstacles, and the anti-collision policies that are implemented. Several studies demonstrate the utilization of Kinect RGB-D sensors in the context of collision prediction, utilizing the production of 3D point cloud data. Furthermore, this study examines the incorporation of sensors to facilitate interaction in virtual environments, using the HTC VIVE PRO controllers as an illustrative example. This investigation focuses specifically on applications in fields such as robotic surgery, where preventing collisions between the robotic system and medical personnel is of utmost importance [34, 35].

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In addition, this discourse explores novel approaches, such as the integration of sensor-equipped robot skins and gesture recognition technologies like Leap Motion, as potential methods to augment human-robot interfaces. The objective is to facilitate uninterrupted communication between human operators and collaborative robots. The aforementioned advancements, in conjunction with algorithms that fuse sensor data, possess considerable promise for enhancing safety and efficiency within collaborative settings in the field of human resources. The next sections offer a more comprehensive analysis of particular subjects, such as hand gesture recognition and diverse approaches to human resources interaction.

The Utilization of Mobile Robots in Industrial Contexts

The importance of mobile robotics in industrial contexts is seeing tremendous growth, wherein Industrial Mobile Robots (IMRs) are assuming a crucial function in present and forthcoming production lines and logistical settings. Autonomous Mobile Robots (AMRs) have become significant assets, revolutionizing working environments by removing the limits on movement that are typically associated with standard Automated Guided Vehicles (AGVs). The utilization of AMRs provides significant advantages in terms of spatial and temporal adaptability, particularly in dynamic manufacturing facilities. The capability to rapidly adjust production sequences contributes to improved efficiency and minimized operational interruptions, effectively addressing the requirements of a market that exhibits a growing preference for personalized products. The design of existing and future production lines is necessarily influenced by these changing dynamics [36-38]. The fundamental focus of working settings is the optimization of processes, which is in line with the principles of Cyber-Physical Systems (CPS).

In the realm of Intelligent Mobile Robots (IMRs), the perception of their environment holds significant significance in order to achieve smooth integration with other Cyber-Physical Systems (CPS) components, going beyond the fundamental task of platform localization during navigation. The introduction of autonomous navigation in Autonomous Mobile Robots (AMRs) necessitates the implementation of effective techniques for Human-Robot Perception (HRP). This is because cooperative operations can be hindered by human operators' perception of autonomous agents in motion. On the other hand, when human perception is poorly handled, it might hinder the successful completion of tasks by mobile robots. In contrast to the predetermined motion courses of Automated Guided Vehicles (AGVs), the movements of Autonomous Mobile Robots (AMRs) may provide difficulties for human operators in terms of interpretation. As a result, significant modifications have been made to the perception systems of conventional AGVs in order to facilitate autonomous navigation and enhance environmental perception in industrial settings [39, 40].

Moreover, with the rising prevalence of fixed-base collaborative robots in production lines, there is a growing interest in the establishment of safe collaborative operations with intelligent mobile robots (IMRs) [41]. Industrial mobile platforms need to enhance their perception capabilities by transitioning from a purely informational approach to a semantic interpretation of their environment. The application of sophisticated human perception in industrial settings is currently gaining traction. However, it has already undergone thorough investigation and implementation in various domains, such as assistive service robotics and agriculture. In these disciplines, robotics plays a crucial role in facilitating process chains [42].

In the field of domestic robotics, a study has been conducted to explore non-intrusive methods for enabling robot-aware navigation. This study focuses on allowing users to define their preferences, which in turn govern the behavior of the robot within specific virtual zones located within a home workspace [43]. Teleoperation situations typically entail collaborative operations between people and mobile robots. In these scenarios, human operators control the robots remotely, while also receiving visual feedback through a 360-degree camera. The visual input is analyzed using Convolutional Neural Networks (CNNs)[44]. The collaborative nature of teleoperation serves to augment the perceptual capabilities of both the human operator and the robot. Various hybrid shared control techniques have been successfully deployed in the context of Human-Robot Collaboration (HRC). One notable example is the integration of electromyography (EMG) signal sensors for command input, together with haptic feedback devices that provide human operators with information on obstacles [45,46].

Studies conducted in controlled laboratory settings have shown that the utilization of optimal collision avoidance and social momentum methods by autonomous mobile robots can result in improved navigation for humans near these robots. This finding underscores the significance of human perception in influencing the performance of mobile robots [47]. Algorithms, such as Robot Perceptual Adaptation (ROPA) [48], have been developed with the purpose of dynamically integrating multi-sensory perception data, specifically emphasizing the task of long-term human partner tracking. Frequently, these methodologies make use of color-depth data obtained from sensors, structured light cameras, and digital luminosity sensors in order to augment perception.

Significantly, there has been a notable focus within the agricultural sector on prioritizing safety and comfort in the context of collaborative interactions between humans and robots [49]. In the domain of autonomous navigation in densely populated surroundings, the utilization of Recurrent Neural Networks (RNNs) is implemented to enhance the motion of mobile robots through the evaluation of image quality and the elimination of extraneous background noise [50]. Bidirectional perception is a

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crucial aspect in the field of help service robotics, particularly in scenarios where robots need to be viewed by users in a natural manner and accurately identify human intentions [51]. The SMOOTH robot project aims to increase the perception of welfare robots by introducing adaptive sensory fusion through the utilization of a multi-sensory neuron model [52]. The integration of data from several sensors, such as LIDAR, stereo/depth, and RGB monocular cameras, has been employed to enhance the perceptual capacities of mobile robots in diverse autonomous navigation endeavors [53].

The presence of several methodologies reflects the extensive range of applications for HRP research, as algorithms are being designed to accommodate a wide array of scenarios involving interactions between humans and robots. The importance of having a cohesive framework for Social-Aware Navigation (SAN) is highlighted in the literature [54], where the recognition of purpose is identified as a crucial factor in attaining trajectories that are conducive to human interaction. Range finder-based systems utilizing SAR (Spatial Augmented Reality) technology have been suggested for use in industrial logistics environments. These systems aim to establish collaborative assembly lines that prioritize the comfort of human-robot interactions, taking into account the principles of proxemics theory [55]. Within the context of logistics warehouses, the utilization of human-aware navigation frameworks involves the implementation of laser scanners and RGB-D cameras for the purpose of detecting humans as a distinct category of obstacles [56]. The integration of Augmented Reality (AR) has been observed in the context of human-robot interactions. This integration involves the utilization of gesture control, eye tracking, and pocket beamers as means to increase communication. There have been advancements in the development of skill transfer systems, which involve the use of mobile robots that learn trajectories from human teachers through the utilization of motion capture sensors [57].

In summary, the many methodologies shown in this study demonstrate the capacity of Human- Robot Interaction (HRI) research to have a substantial influence on industrial environments. The development of algorithms and systems that provide smooth and secure cooperation between human workers and mobile robots exhibits considerable potential in this regard. Numerous algorithms have been specifically developed to possess adaptability in diverse situations involving both humans and robots. This characteristic aligns with the dynamic nature of collaborative robotics and automation [58].

Emotional Contagion: An Examination of the Nature and Mechanisms

The role of facial expressions in human social communication is of utmost importance, as they serve as a universally understood form of nonverbal communication that surpasses cultural barriers. Emotions such as wrath, disdain, disgust, fear, joy, sadness, and surprise are universally acknowledged within various cultural contexts, serving as fundamental constituents of human encounters. These emotions play a crucial role in cognitive processes, assisting individuals in the interpretation and navigation of the intricate aspects of the world [59]. Moreover, the emotional states of individuals have a significant impact on their motivations and activities, resulting in a cascading effect on interpersonal relationships. Emotional contagion, a fascinating psychological phenomena, involves the transmission and acquisition of emotions exhibited by individuals within a social context [60]. The aforementioned process functions in a bidirectional manner, wherein individuals can experience emotional impact from others, whether it is done intentionally or unconsciously. One possible explanation for this behavior might be attributed to the mirror neuron system, which is a brain network hypothesized to be responsible for our capacity to empathize with and imitate the emotions of others. This phenomenon transcends the human species and is seen in non-human primates, including dogs, who exhibit emotional states through their body postures [61].

The process of emotional contagion can be shown to occur in three distinct stages, namely mimicry, feedback, and contagion. In the initial stages, when individuals perceive an emotional state in another person, they frequently exhibit spontaneous mimicry of their actions and facial expressions, thereby facilitating the development of empathy through the simulation of comparable affective experiences. Following that, the stage of feedback ensues as an individual comprehends the emotional expression being transmitted by another individual. This cognitive process enhances the subjective emotional experience by assimilating the observed feeling into one's personal repertoire, so augmenting the emotional connection. The significance of these stages has been extensively examined in several studies across diverse situations. Previous studies have examined the impact of staff' emotions on client experiences, emphasizing the significance of pleasant emotions in the context of service encounters [62]. Nevertheless, there has been a lack of focus on the examination of negative emotions within service environments, specifically in the realm of human-robot interactions. With the broadening scope of service provision, encompassing not just human contacts but also interactions involving service robots and anthropomorphic robots, the significance of emotional contagion dynamics is growing. The investigation of how emotions are conveyed in human-robot interactions is an emerging field of research, providing valuable insights into the changing dynamics of service encounters. The rise of service robots highlights the necessity of investigating emotional contagion and its ramifications within the developing field of human-robot interaction.

The Importance of Emotion in Human-Robot Interaction

The field of human-robot interaction encompasses a wide range of academic disciplines, such as psychology, social sciences, cognitive science, artificial intelligence, design, engineering, and computer science [63]. The utilization of a multidisciplinary approach allows for the comprehensive examination of the various

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aspects pertaining to the interactions between humans and robots, with a specific focus on service contexts. The examination of service robots within various contexts enhances our comprehension of customer encounters and presents promising prospects for the implementation of such robots. Ongoing discussions around safety and security persistently influence the development of this sector, with certain stakeholders envisioning anthropomorphic and humanoid robots as potential catalysts for future advancements in social practices across diverse disciplines.

The role of emotions has become crucial and influential in the context of human-robot interaction. They have a crucial function in promoting active participation and collaboratively generating significant experiences within this particular framework [64]. Research has indicated that individuals are more inclined to place their faith in robots that exhibit good emotions. Robots that exhibit emotional expressiveness are frequently favored in comparison to their neutral counterparts. This effect exhibits a strong correlation with the idea known as the "uncanny valley," which posits a connection between the degree of human resemblance and the manifestation of emotional expressions. Nevertheless, humanoid robots that possess human-like qualities but are not flawless have the potential to evoke adverse emotional reactions among individuals who observe them [65].

Current scholarly investigations have focused on the complex dynamics of emotional interactions between robots and humans. The incorporation of emotional factors into human-computer interactions has been observed to increase conversational dynamics and user experiences, particularly when chat bots convey messages with a happy tone. The investigation of emotions exhibited by robots, namely the Nao robot, in service-oriented positions has yielded insights indicating a higher likelihood of emotional contagion with positive emotions as opposed to negative ones. In the context of healthcare service, it has been observed that negative emotional expressions, such as rage, tend to be identified more rapidly than positive emotions [66]. This suggests a heightened sensitivity to contextual cues.

The pursuit of fostering trust and collaboration between humans and robots within the realm of healthcare services has resulted in the creation of robots that possess the ability to exhibit empathy in accordance with the emotional states of their users. These robotic systems employ facial expressions, namely eyebrow and mouth movements, as a means of communicating a diverse array of emotions, thereby enhancing the overall user experience [67]. It is noteworthy to acknowledge that the existing body of literature on emotionally capable robots primarily focuses on humanoid robots, such as Nao and Pepper, which bear a resemblance to human form. The incorporation of artificial intelligence into several sectors, exemplified by the Henn-na hotel in Japan, underscores the significance of anthropomorphic robots as primary representatives. Research conducted in this field has provided evidence that positive emotional expressions exhibited by anthropomorphic robots can augment the perception of service quality, interpersonal warmth, and customer satisfaction. These findings highlight the increasing anticipation that artificial intelligence possesses the capability to comprehend and react to human emotions, thereby facilitating personalized experiences [68, 69].

Methodology

In this section, we will outline the methodology employed in this study. The main aim of this study is to investigate the complex relationship between emotional expressions produced by robots and the emotive reactions of consumers, utilizing machine learning methods for analysis. The present study aims to evaluate the range of emotional expressions exhibited by robots, encompassing a diverse set of categories such as anger, contempt, disgust, fear, happiness, neutrality, sadness, and surprise. Concurrently, the assessment of consumers' affective responses involves the identification and categorization of sentiments into positive, negative, and neutral categories. For the purpose of this inquiry, Sophia, an innovative humanoid robot with the ability to display over 60 human emotions, was selected as the central subject. The development of Sophia, created by Hanson Robotics in Hong Kong, is a noteworthy achievement in the field of robotics. Notably, Sophia was granted Saudi Arabian citizenship in 2017, further highlighting her significance in this domain. Sophia utilizes deep learning and sophisticated material technology to replicate the primary facial muscles found in humans, so enabling her to effectively express a range of emotions including joy, perplexity, surprise, and grief, among others [70].

It is imperative to acknowledge that although Sophia harbors aspirations to work in healthcare, customer service, and education, she has not yet had practical experience in these service-oriented sectors. This study utilized a systematic methodological approach, consisting of six separate processes, which will be further elaborated upon in subsequent sections. The methods outlined in this study were carefully crafted to investigate the complex relationship between emotional expressions made by robots and the affective responses of consumers. This research provides insights into the possible influence of emotionally expressive robots on different sectors, such as service industries.

The Development and Validation of the Scale in User Studies

In order to develop a comprehensive and significant scale, it was necessary to first conduct a crucial initial phase known as the pretest phase. The primary objective of this pretest was to evaluate the level of semantic duplication present in different items. The aim was to avoid any possible weight bias, commonly known as the "redundancy gain effect," that may arise from incorporating comparable items in the process of developing the scale. In order to aid the assessment, a selection of forty-four items was compiled from various sources, namely the Godspeed scale, Warmth and

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Competence dimensions, RoSAS (disturbance dimension), and the De-humanization theory (Human nature dimension) (please refer to Table 1 for further information). During this phase, a significant emphasis was placed on investigating the potential correlation effects within de-humanization items and ensuring the distinctiveness of positive and negative dimensions. In order to accomplish this objective, a preliminary assessment was carried out, involving a sample of twenty individuals. Each participant was assigned the duty of evaluating four different robots, namely Nao, Yumi, Spot, and Meccanoid.

The evaluation was conducted using the Haslam de-humanization taxonomy, which comprises a set of twenty questions. The findings of this assessment unveiled statistically significant relationships among all combinations of elements. As a result, in order to address potential challenges related to semantic differentiation, it was determined that only the five positive elements from the mechanical de-humanization taxonomy would be presented [71-73]. The purpose of this decision was to reduce the potential for participants' replies to be influenced by a positive or negative semantic bias, which is commonly noticed when using items that are semantically divided into two categories. Furthermore, the preference for employing positive items over negative ones might be attributed to the presence of a positivity bias, which has the potential to influence the interpretation of negative items. This tendency may lead to increased ambiguity and variability in the judgements made by participants. Following this, a total of forty-four terms were administered to a sample of 118 individuals who spoke English as their first language. These participants were recruited through online platforms, with the primary objective of determining any synonymous relationships that exist within the given word list.

The participants were provided with instructions to differentiate synonyms by employing a drag-and-drop method to identify phrases that they perceived to have similar meanings. A threshold for synonym agreement was established at 80%. Items that attained agreement levels surpassing this threshold were consolidated into a singular prototype item, thereby guaranteeing a more streamlined and efficient scale [74,75]. In brief, the thorough pretest phase played a crucial role in enhancing the scale through the elimination of redundant elements and the optimization of item clarity and dependability. This process has laid the foundation for conducting more detailed user research.

Prospects for Advancing Culturally-Sensitive Robotics

The comprehensive examination of prior scholarly works within this manuscript has shed light on the significant influence that culture exerts on the manner in which individuals engage with social robots. The presence of diverse approaches employed in different research may be subject to criticism due to their ability to introduce confounding factors [76]. However, it is important to note that these variations also highlight the extensive range of robotic agents that are currently accessible. The presence of this diversity offers a valuable opportunity for conducting future research in order to comprehensively and rigorously investigate this interdisciplinary field. In order to enhance our comprehension of the dynamic relationship between culture and human-robot interaction (HRI) [77], forthcoming research endeavors should prioritize the implementation of systematic and rigorous replications to validate and expand upon the existing corpus of empirical findings. In order to accomplish this goal, it is important to conduct experiments with rigorous control measures and make well-founded choices about the design of studies and the statistical power in research publications. Furthermore, it is essential to incorporate a diverse range of cultural examples from many societies in order to rectify the existing issue of particular countries being disproportionately represented. Additionally, this approach allows for an exploration of cultures that extend beyond the traditional Western and Eastern dichotomy. While the current corpus of knowledge primarily centers around neuro-typical adults, it is imperative for future research endeavors to expand their purview to encompass other population groups, encompassing individuals across various age cohorts and developmental phases [78]. It is crucial to comprehend the intersection between a wider spectrum of human wants and interests, cultural backgrounds, and their influence on the quality of interactions with artificial agents.

Furthermore, it is recommended that future studies undertake a more comprehensive investigation into the intricate dynamics between cognitive styles, culturally generated preferences, and motivational elements, such as a user's level of commitment towards a robot or their assessment of the robot's effort during interaction [79]. The understanding gained in this field has the potential to greatly influence the creation and advancement of culturally-sensitive robots, potentially leading to a transformative change in the field of robotics research. Incorporation of longitudinal study designs in forthcoming studies is vital in order to yield essential insights on the potential evolution of individuals' attitudes and acceptance towards robots, both longitudinally and throughout various developmental stages. By engaging in partnerships with established longitudinal studies and those that include the field of human development [80], valuable insights can be gained regarding the enduring patterns of experiences and relationships with robots. For example, this line of inquiry could explore if specific cultural groups have higher levels of adaptability or a more rapid formation of favorable perceptions and attitudes towards robots in comparison to other cultures. On the other hand, an examination might be conducted to delve into the difficulties that certain cultures may present in terms of embracing robots in socially supportive capacities [81].

Moreover, it is imperative to investigate the integration of culturally-sensitive indications into robot programming in order to mitigate the potential negative views that may

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arise from technological errors in human-robot interactions. Interdisciplinary collaboration among engineers, social robotics experts, psychologists, and sociologists is necessary for this endeavor. As the development and integration of robots' progress in various aspects of society, it is imperative for future research endeavors to explore the degree to which individuals continuously exhibit a preference for robots that exhibit similarities in their actions, movements, or physical appearance.

This study has the potential to provide clarification on the contentious phenomena known as the "uncanny valley." These intricate inquiries beyond superficial characteristics and require input from a wide range of intellectuals, encompassing scientists, artists, sociologists, anthropologists, psychologists, philosophers, and neuroscientists [82]. The thorough integration of diverse cultural perspectives and the deliberate consideration of the cultural backgrounds of robotics producers are essential factors in informing the behavior and functionality of robots. Furthermore, there is a significant potential for investigating the influence of intercultural backgrounds on the way users perceive, experience emotions, and engage in cognitive processes during Human-Robot Interaction (HRI). Gaining an understanding of the perceptions and interactions of persons who have relocated or resided in foreign countries with robots can yield useful insights for the future advancement of culturally-sensitive robotic agents. At the current juncture, where intricate choices concerning the trajectory of socially-interactive robots are being made, it is imperative to recognize the significance of multidisciplinary and culturally-informed research. Such studies will have a crucial impact on the development of future robotics and its assimilation into our heterogeneous society [83].

In conclusion, the field of socially interactive robotics has recognized the importance of incorporating cultural factors into the design and development of robotic systems. By integrating cultural knowledge and understanding, researchers want to create socially intelligent robots that can understand.

Towards Safe and Effective Collaboration: Conclusions and Future Trends in Human- Robot Interaction

Culture plays a significant and influential role in shaping and unifying civilizations by fostering shared perceptions and practices among individuals. This review has explored the convergence of culture with the rapidly evolving field of social robots, analyzing our preconceived ideas and reactions while engaging with these artificial entities. Moreover, this phenomenon has prompted significant inquiries on the appropriateness of customizing social robots to particular cultural environments versus developing them to be adaptable to the wide array of cultural backgrounds they may encounter. The assertion made by Thomas Ramge [84], a technology writer, on the influence of cultural attitudes on the pace of innovation adoption highlights the significant role that culture plays in shaping our interaction with technology. Although the theory lacks complete empirical validation at present, it serves as a crucial reminder for professionals engaged in the realm of social robots. Disregarding the impact of culture within this particular field is a risky endeavor. This review has demonstrated the influence of cultural backgrounds on individuals' inclinations towards various robotic agents, encompassing both verbal and non-verbal social cues at a nuanced level. Gaining a comprehensive understanding of this intricate nature is vital in order to grasp our responsibilities as societal participants within the global arena, particularly within the framework of a progressively interlinked global community. In this paper, we discuss the conclusions drawn from our research on human-robot interaction and present future trends in this field, with a focus on achieving safe and efficient collaboration between humans and robots. The domain of human-robot interaction (HRI) is undergoing rapid development, particularly within industrial contexts where the utmost importance is placed on safety and collaboration. The recognition of intentions by robots is becoming increasingly important, as it facilitates proactive collaboration between people and robots. The prevalence of human-robot collaboration (HRC) is growing in modern production settings, requiring robots to possess the ability to adjust their behaviors in response to the presence and intentions of humans [85].

Nevertheless, it is imperative that the collaborative environment established for both humans and robots does not undermine overall efficiency and output. In the context of future smart manufacturing processes, it is imperative that robots adhere to the dual imperatives of safety and efficiency. The improvement of human-robot perception (HRP) is crucial not only for ensuring safety but also for attaining the overall key performance indicators (KPIs) in industrial processes. The establishment of effective collaboration between human workers and robotic systems will serve as a crucial component inside industrial processes that are partially automated.

This research has conducted an analysis of several sensors and methodologies utilized for detecting and reacting to human operators in industrial settings, specifically addressing a wide range of robotic systems. Vision sensors, specifically RGB-D cameras, play a crucial role in detecting and analyzing human presence.

The integration of several sensor modalities, situated on both robotic platforms and human agents, presents novel prospects for collaborative endeavors and a wide range of practical implementations. Laser sensors are frequently employed in conjunction with vision sensors in mobile agents and manipulators to facilitate navigation and enhance human perception. Although unconventional sensors show promise, their utilization is constrained by the difficulties associated with interpreting non-traditional outputs. Numerous human-robot interaction (HRI) techniques employ artificial intelligence (AI) algorithms for the purpose of object recognition and human

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behavior analysis. The potential for HRC applications in the future is promising, as it involves the utilization of both conventional and new sensors in intelligent manners. The integration of several sensors across various domains such as assistive service robotics, agriculture, and robotic surgery might enhance the effectiveness of industrial human- robot collaboration (HRC) applications. As we traverse this dynamic terrain, it becomes evident that the symbiotic relationship between humans and robots will persistently influence several sectors, surpassing conventional limitations and introducing novel opportunities for cooperation and advancement.

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