Chapter

Introductory Chapter: Human-Robot Interaction – Advances and Applications

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1. Introduction

Recent advances in robotic technology are bringing about robots better suited to perform tasks and applications in which robots are interacting directly with people in their everyday environments, both at home and in the workplace. Human-robot interaction (HRI) is beneficial because robots have been shown to deliver an emotional response to humans and humans find robots engaging. Additionally, robots can integrate into everyday settings without difficulty and can be perceived by humans as active social agents, meaning they can complete the programmed tasks with total control, independence, and intentionality. With HRI, a user's experience of interaction varies from person to person and is influenced by many factors such as physical context of the environment, cultural context, thoughts and feelings toward the robot, and social nature [1].

HRI is also an important development because it allows robots to be directed by humans to complete certain challenging and hazardous tasks, notably in an industrial setting. With modern computational algorithms programmed into the environment, HRI can increase productivity and reduce downtime and task interruptions [2]. Additionally, HRI is a beneficial solution to compensate for a lack of human labor force in a certain setting, due to various factors such as extreme conditions or low pay. The lack of human labor hurts the local or large-scale economy as it means a lower production supply, and this issue can be resolved potentially by incorporating robots into the scene. However, fully replacing humans with robots would mean a larger initial investment and would eliminate availability of jobs. Instead, robots could be incorporated alongside human workers as a means to improve human comfort and optimize productivity. HRI is a significant modern approach to improve the functioning of everyday settings and has countless advantages and applications.

2. Collaborative and humanoid robots

Collaborative robotics is the field of study that involves using human demonstration to teach robots different skills. The robot can learn to recognize goal-oriented actions and understand human actions and verbal and nonverbal communication. While robots can learn from imitation, in a complex environment where different situations arise, imitation is not enough to make the robot able to function in the complex environment by itself without human involvement. Collaborative robots can work alongside humans on tasks and can provide assistance by responding to user requests for help or by automatically detecting at what point to assist. Thus, in a collaborative environment, both parties must have the ability to refer to objects in the shared space. Humans can use a combination of various techniques, including sensorimotor signals, verbal cues, pointing gestures, and gaze to communicate to the robot to handle a certain object [3].

Humanoid robots are designed to resemble humans in terms of appearance. They have continued to increase their roles in everyday human environments as coworkers, companions, trainers, and assistants. Humanoid robots are created to be similar to humans both in outward design and language and gesture behaviors. In designing robots to play roles alongside humans, it is important to investigate how humans interpret and emotionally respond to the robot to allow for a smooth incorporation into our everyday lives. Humans have been demonstrated to engage with and respond especially well to humanoid robots. Humanoids were seen as having more moral responsibility, observing social norms, and generating formal expressions from their human counterparts communicating with them [4].

Telerobots perform routine tasks under supervisory control by humans. The human supervisors monitor and reprogram the robots at irregular intervals to execute different pieces of the higher-arching task. Telerobots are designed to simplify communication with humans and improve the ease of human control. It is important that the telerobot is directed to complete the task as efficiently as possible while the human operator is comfortable controlling the telerobot, even during chaotic situations. Moreover, they can be instructed to carry out tasks in environments that are hazardous or inaccessible to humans. Additionally, telerobots have greater precision than human hands, which may come useful in many different settings such as surgeries [5].

Figure 1.
Overview of significant applications of human-robot interaction.

Human-robot interaction is an area of research that involves developing and improving the most optimal robots that cooperate with humans. An overview of current and potential applications of HRI is illustrated in **Figure 1**. In the subsequent sections, we discussed each of these applications and challenges in detail.

3. Space exploration

Emerging technologies in HRI look promising to efficiently combine the capabilities of astronauts, remote operators, and robotic assets into human-machine teams that can effectively communicate for the purpose of space exploration. These technologies have been carefully planned to meet sustainability requirements and minimize the use of resources. The use of HRI can be especially beneficial to complete space exploration tasks such as collecting environment and mapping information, providing situational awareness of the scene and surroundings, developing and maintaining infrastructure, and providing mobility support to the astronauts. The future of successful space exploration will be heavily influenced by the ability of the human and robot to demonstrate strong communication through both gestures and dialogue and to collaborate with one another for problem-solving [6].

One such HRI technology is Explainable AI (xAI), which can provide a virtual deep-space environment simulation that can show how the space rover will behave in a certain scenario, and the human controller can prepare strategies and informed decisions to apply during the actual deployment. An additional technology is virtual, augmented, and mixed reality (VAMR), which provides visual displays, situational awareness, and additional functionality and communication. The navigation cues and technology recognition that VAMR provides can guide the rover in effectively investigating an unfamiliar terrain. Another emerging technology is adaptive and adaptable automation. Adaptive control is where the robot automatically adjusts control parameters as a system response, while adaptable control is where the human controller operates manual system changes. This technology is an optimal design that balances the self-adjusting robots and the significance of human monitoring, aiding the efficiency and safety during space exploration [7]. The use of HRI along with the emerging technologies in the area of space exploration expands the possibilities for new learnings and discoveries.

4. Military

The future of military robots puts soldiers and robots as teammates, where the soldier and robot can share the task load and accomplish the goal together. In this environment, the robot is an important entity that acts autonomously and intelligently and can simulate team behaviors such as communication and coordination [8]. Robots are able to complete operations in environments that are harmful to the soldiers, and this keeps the soldiers and civilians safe. These operations include clearing buildings, search and rescue in disaster areas, detecting explosives, and surveillance activities. Additionally, military robots can support the soldiers by gathering data to improve situational awareness, transport equipment, efficiently distribute supplies, facilitate commanders' decision-making, and protect the soldier from hostile attacks.

To make HRI integration possible in this setting, a multitude of factors have to be considered including operating environments, task difficulty, soldier's comfort level with the robot, and communication and decision-making for both the soldier and robot. Emerging technologies, both modeling and simulation systems, have been developed to identify and resolve potential integration issues. One such modeling system is the Improved Performance Research Integration Tool (IMPRINT). IMPRINT analysis demonstrated that integrating HRI into a mission with soldiers mounted in carrier vehicles or on horses would cause overload issues, and, therefore, gunners were a better-suited group for HRI integration. Modeling technologies such as IMPRINT can be used to set guidelines that can be validated through simulations, and the models can be revised and improved. Simulations are particularly helpful to determine the effects of adding complexity to the tasks, considering potential strategies to reduce overload and investigating ways to improve performance while carrying out the military task [9].

5. Healthcare

Robots taking on roles as healthcare workers have incredible benefits for the population. These include accuracy in treatment performance, strong working speed, reducing workload for the human healthcare worker, organization of daily routine, optimizing healthcare resources, and resolving simple problems so that the patient does not have to visit the doctor [10]. The elderly population is increasing in size and the available supply of healthcare workers concerningly cannot support the population increase of this demographic. This demographic especially has the potential to improve well-being as a result of interaction with healthcare robots. Robots as healthcare workers allow elderly adults to be at home later in life instead of in an elder care facility, which reduces financial and emotional stress for the patient and the family, lowers costs, and helps elderly adults retain independence and be happier and healthier.

Healthcare robots can serve in rehabilitation or social roles. Rehabilitation robots can perform tasks or make tasks easier for the user, while social robots are for elderly adults to interact with and have as a companion. It is important to consider the concerns and needs of elderly adults during the robotic design process so that the user will accept the robot. Some elderly adults have demonstrated to be skeptical of accepting the robot due to it being a rapid jump in technology and the potential privacy issues it may present, but they are more likely to accept the robot if it can perform tasks that they find useful [11].

Conditions that the elderly population face that HRI provides technological improvements for include physical and functional decline and cognitive decline. Healthcare robots can assist elderly adults with tasks that become more difficult due to these conditions. Emerging technologies can help with tasks impacted by physical and functional decline such as cleaning, heating food, and sorting laundry. Robotic developments in the areas of mobility assistance and other activities such as bathing have also been in the works. Healthcare robots make these activities safer and more comfortable for the patient. Other technologies help patients monitor their health conditions and provide appointment reminders. Robotic technologies help with cognitive decline by providing cognitive training exercises that keep the patients engaged and stimulated.

The COVID-19 pandemic has only furthered the growing shortage of healthcare workers. Throughout the pandemic, healthcare robots were used for a high variety of purposes, including health screenings, transportation of medical goods, and even direct patient care. The robots provided a multitude of benefits, including minimizing human contact and, therefore, reducing transmission rates and decreasing the workload on healthcare workers. The technologies used during the pandemic were adapted from preexisting technologies, as this approach was more efficient than developing new technologies during a crisis. For example, the Guangzhou Gosuncn Robot Company developed robots originally intended to be used for policing, but these robots were modified and equipped with powerful cameras to screen the body temperature of up to 10 people at once and detect if an individual is wearing a facemask. The COVID-19 pandemic demonstrated how important it is to formulate reliable protocols for how to adapt preexisting technologies for healthcare purposes if and when a future pandemic or crisis occurs [12]. This will allow for the most organized treatment possible and the most efficient patient path to recovery.

6. Manufacturing

HRI provides benefits in manufacturing in terms of productivity, safety, and working conditions. HRI is an approach that complements the strengths of humans and robots in manufacturing. This approach would make manufacturing a more sustainable career for individuals in the long term, as the incorporation of robots allows workers to avoid hard physical work. This also means a reduction in illness rates. Additionally, productivity increases with this approach because robot workers do not need downtime or on-the-job training. HRI can reduce running costs and speed of assembly, and improves readability and precision. Multiple factors need to be considered when implementing HRI into a setting to optimize performance. These include movement speed of the robot, distances between humans and robots, robot noises, trajectory of the robot, and physical appearance of the robot [13].

Robots can especially be helpful in assisting humans in the areas of delivering tools and parts and holding manufacturing equipment objects or objects in the process of being assembled. Robots can contribute accuracy, speed, and consistency to the setting, while humans contribute organization, management, and more cognitive assets. By sharing the workspace, situation awareness, danger perception, and enrichment communication are promoted. Modern robot designs often are programmed with advanced sensing, joint compliance, and artificial intelligence. Robots can play impactful roles in individual parts of the manufacturing setting, or they can contribute to the setting in a broader sense. For example, in a narrower role, the robot can control manufacturing tools or feeder equipment such as conveyors and loaders. In a broader sense, the robot's state-of-the-art design and advanced technology give it the ability to contribute to process flow control and the maintenance of workplace safety.

Manufacturing settings vary in many ways, including plant size, wealth, and typical size of produced batch. HRI is beneficial for industrial settings of all sizes, so it is important to find ways to make HRI more accessible for small and mid-size enterprises (SMEs), which have fewer resources, to begin with, and are less likely to take risks with their manufacturing model [14]. SMEs play a critical role in the economy, and this emphasizes the need for SMEs to adapt to modern technologies so that they can optimize consumerism. In the UK, 99% of the 5.6 million businesses are SMEs.

One approach to increase HRI in SME settings is to identify individual motivation by creating a model that supports fulfilling an overall goal by achieving predefined subgoals. For example, faster and more efficient destocking of assembled parts contributes to greater productivity. The predefined subgoal, in this case, is the faster destocking of assembled parts, which is an area that HRI can demonstrate strong support to. This approach allows the SME to identify the most suitable technologies for the assembly setting without having to use up resources to trial different technologies that may or may not be optimal. HRI has incredible benefits for manufacturing, and it is important to determine the most efficient way to incorporate it into the setting.

7. Education

HRI has shown promise in the area of being learning companions for children in classrooms and at home, and as tutors to help students better understand the content. HRI has been demonstrated to be beneficial for students of all ages, including preschool, elementary school, and post-secondary education. The use of HRI can help teach a broad range of disciplines, including STEM, languages, and handwriting. Aside from adaptability to a wide range of disciplines, robots provide additional benefits in education settings such as engagement, motivation, improving the learner's self-esteem, and providing empathetic feedback. When designing robots for this purpose, it is important for developers to consider the social conscience of the robot and its ability to collaborate with educators.

At the preschool level, emerging technologies are often geared toward improving social integration and engaging the children in constructive learning, meaning the learner is actively involved in knowledge construction. The technologies are incorporated into storytelling in the classroom, as storytelling is essential for children's language and creative development. In this setting, the robot would act as a storyteller to the children. Adopting HRI into storytelling has demonstrated a positive impact on the children's enjoyment and engagement. It has also shown positive results in rehabilitation, learning English, and creativity enhancement [15]. HRI is additionally adaptable to different educational environments, such as a playground or schoolyard, which gives the children further room to learn and grow.

At the elementary school demographic, robots have taken the role of tutors in the area of language learning. In one study, 10- to 11-year-olds were formulated with the task of learning an artificial language. The robots taught the children a 30-minute introductory lesson, and ideally, the students would be able to form simple sentences after the lesson. The sociability of the robot was demonstrated to be a crucial factor in terms of both engagement and performance. The students had stronger engagement and performances when the robot showed role model behavior, personal feedback, empathy, and communicativeness [16]. These findings further support the importance of considering sociability when designing a robot for tutoring purposes.

Personalization has been a recent subject of interest when designing a robot for the educational setting. The extent that tailoring to an individual's strengths and weaknesses is beneficial to that individual's learning, is not fully understood. This subject matter was investigated in a study where undergraduate and graduate student participants were tutored by a robot in solving grid-based logic puzzles. Participants received lessons from both personalized and non-personalized robots. The findings supported that even relatively simple personalization shows significant learning benefits, as personalization led to stronger performance and faster speed of solving the puzzle [17]. This demonstrates that personalization and adaptability is other important quality to keep in mind when designing the most optimal robot for learning. Additionally, it makes clear that HRI is a beneficial approach for post-secondary students and not just for younger students.

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8. Personal and societal applications

HRI has emerged in society working with people in airports, shopping malls, and care centers. With robots entering public spaces more often, this comes with the responsibility of having to maintain a positive image and appearance, as well as behavior that reflects well on society. It is critical that robots for these settings are designed to be accepting of all people and not promote gender stereotypes or ageist views. Robots in public settings have the capacity not only to be respectful to those being helped and not show social biases, but they can also go as far as to be an example and advocate for positive social change. They can bring about a positive impact on a wide range of issues in society such as homelessness, poverty, and refugee crises. To develop robots that represent social empowerment, it is important to consider how robots are shaped as part of society's socio-political dynamics.

Airports are one area where the incorporation of HRI can be particularly helpful and improve passenger experience in the setting. Airports are often overwhelming for passengers due to the large crowds, frequent announcements, and confusing screens and signs. The atmosphere of the airport setting should be considered when designing a robot to fulfill the needs of the passengers. A large robot that can communicate using nonverbal gestures is favorable because airports are crowded and noisy and it is important for the robot to be easily accessible and understood despite the surrounding noise. It is also important for the robot to be able to accommodate the hearing impaired, which could be done by having a display space showing text and images. Additional factors to look out for include affordability, range of dynamic motion, and suitability for the particular environment [18].

Retail is a separate area where HRI can benefit customers. HRI can improve service quality by helping customers navigate a store to find products and information, receive personalized guidance on products, order online for delivery or pickup, and complete purchase transactions. As HRI makes it easier for customers to shop, this in turn increases sales, reduces labor costs, and provides an engaging retail experience. Robots in retail additionally have advantages over human staff, as this approach minimizes human error and allows for more rapid service processes. Human staff often experience physical fatigue and mental strain when performing service tasks, and their work experience includes training time and downtime, which takes away from the opportunity for productive sales. Humanoid robots, notably, can mimic human communication and social interactions, and this makes them strong candidates for integration into retail settings. When designing a robot for this setting, it is critical to consider the robot's emotional aspect for an optimal customer experience. The use of HRI in public environments is promising as a means to improve personal experience and have a positive socio-political impact on society as a whole.

9. Challenges in HRI

It is difficult to design a robot that allows for accurate interaction and communication. There is still work to be done to look for creative ways to improve the capacity of robots in understanding human actions and responding appropriately. With the ability to recognize human hand gestures, there is still room for error due to the complexity and high degree of freedom of human hands. More effective robots should combine multi-modal features, and be able to recognize posture, facial expressions, and voice intensity. This comes along with developing more complicated and powerful sensors, which further makes equipping the robot difficult. Additionally, for optimal interaction, robots need a mechanism to foresee and predict upcoming actions. The complexity and inconsistency of human actions make designing this mechanism a challenge. In HRI, robots also need to be sensitive to surroundings, as well as clutter, lighting changes, and depth perception. It is important and at the same time difficult to consider all of these factors together.

HRI not only has certain design challenges, but it also has some ethical parameters. It is important to keep in mind both helpful and harmful behavior with regard to robots and robotic assistance. The use of robots for killing activities in warfare, for sexual pleasure, or to care for emotionally unstable target groups is a particularly sensitive subject matter. Robots also have the potential to make humans less motivated to work, or unwilling or unable to fulfill certain tasks, even simple ones. There are multiple perspectives on robot rights, treating robots respectfully, and if ethics even apply to the robot itself altogether. An additional ethical issue is who regulates robot use, and who is held responsible if a robot causes damage to a human or property. This also brings into question who is responsible for robot malfunctions as well as the proper way to dispose of robots. HRI also has privacy issues, as the process of consenting to give out personal information to the robot is not concrete. Another potential issue is the robot's physical appearance if it is inadvertently built to match any biases of the designer or embody discrimination through having Euro-centric or overly feminized features. HRI has many ethical issues that are important to take into perspective and find ways to avoid possible harm to robots or users.

10. Conclusion

HRI is evidently a promising modern approach with great benefits in both home and work sites. Some of these benefits include providing engagement, accuracy, productivity, and adaptability. Collaborative robots, humanoid robots, and telerobots all have endless possibilities, and there is still improvement space to further explore the promising potential that these technologies offer. When designing a robot for optimal performance, there are many important factors to keep in mind including physical appearance, behavioral traits, and suitability for a particular setting. Emerging technologies, including simulation systems and virtual displays, are helpful in testing and improving a robot's capabilities and preparing for integration. In the subsequent chapters, this book will discuss modern HRI applications in multiple aspects and will touch upon different perspectives and experimental methodologies to develop HRI environments. Emerging technological advancements in HRI and the strong evidence of the incredible benefits make HRI an excellent approach in everyday settings with even more exciting growth to come.

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