Revolutionizing Interaction: Embodied Intelligence and the New Era of Human-Robot Interaction

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I. INTRODUCTION

The emerging field of embodied intelligence in human-robot interaction (HRI) has the potential to bring transformative changes across various industries. Focusing on applying AI methods and technologies to enhance the effectiveness of HRI, we analyze the challenges of developing next generation HRI and opportunities they may present.

II. EMBODIED INTELLIGENCE HRI SYSTEM

Embodied Intelligence-driven HRI is a concept from a multidisciplinary field, emphasizing that intelligent behavior is not merely the product of the brain or computer algorithms, but the result of the interaction between the human body and the robot. Its core aspects include: the interaction between the body and the environment, the unity of perception and action, adaptation and learning, and the integration of multiple disciplines. Figure 1 provides a comprehensive schematic illustration of a HRI system propelled by embodied intelligence. This conceptual framework serves as an intricate platform that intricately interconnects three pivotal entities—humans, robots, and the natural environment—leveraging a sophisticated array of advanced technologies. These encompass multiple sensors, multi-modal data fusion, intelligent communication techniques, and artificial intelligence algorithms. The integration of a Body Area Network surrounding humans is achieved through the meticulous design and implementation of a data collection system, which seamlessly incorporates various sensors. This system is meticulously developed to encompass diverse communication methods, including specialized gateways tailored for HRI applications, thereby facilitating the comprehensive collection and storage of a myriad of data. Similarly, corresponding configurations have been implemented around the robot to optimize and streamline its interactive capabilities.

The schematic representation elucidates the intricate dynamics among three key elements: human-robot, human-environment, and robot-environment. The context of human-robot interaction is characterized by embodied intelligence, while the environmental component encompasses fundamental information such as meteorological data. The outer circle of this conceptual model encapsulates feedback or signals exchanged between humans and robots in a bidirectional manner. In contrast, the inner circle delineates the actions undertaken by humans and robots within the environment, coupled with the consequential feedback provided by the environment to both humans and robots. This holistic system ensures the seamless collection and processing of multimodal data, fostering fluid and secure interactions between humans and machines.

III. CHALLENGES

Despite the existing HRI technologies being quite advanced and diverse, facing the broad range of application areas worldwide and the rapidly growing variety of technologies, Embodied Intelligence and HRI still confronts numerous challenges in its future development.

A. Technology

Robotics: In the developing field of robotics, researchers are addressing the challenge of integrating diverse functionalities into single robots by creating specialized robots for specific domains, a strategy termed "Robot+". For instance, assistive robots under "Robot+assistance" are designed to be user-friendly and customizable, interacting through touch panels and voice commands, with a focus on safety, especially in unpredictable environments. This includes essential safety features for interaction with vulnerable groups. Other categories like "Robot+industry" and "Robot+clinical" each have unique focuses, such as cost-effectiveness and high efficiency for industrial robots. These specializations within the "Robot+" framework cater to distinct challenges and needs, showcasing the varied and progressive nature of robotics.

Smart sensing: Intelligent sensing technology, capable of sensing environmental changes and intelligently responding, ranges from basic data collection to advanced data processing and decision-making. This field has seen the emergence of sophisticated technologies like electronic skin, flexible wearable devices, and advanced imaging in the Metaverse and holographic projections. Electronic skin mimics real skin's tactile responses, and flexible wearables adapt to the human body for a natural experience. The Metaverse offers immersive experiences, extending virtual reality, while holographic projections create lifelike 3D images. In HRI, the integration of intelligent sensing is vital for accurately perceiving and interpreting complex human behaviors and emotions, thereby enhancing the user experience.

Communication: In HRI, complex systems require processing large amounts of sensor data, where data volume and transmission speed are key to interaction quality. This is especially relevant in the Metaverse, where AR and VR technologies create immersive experiences and generate

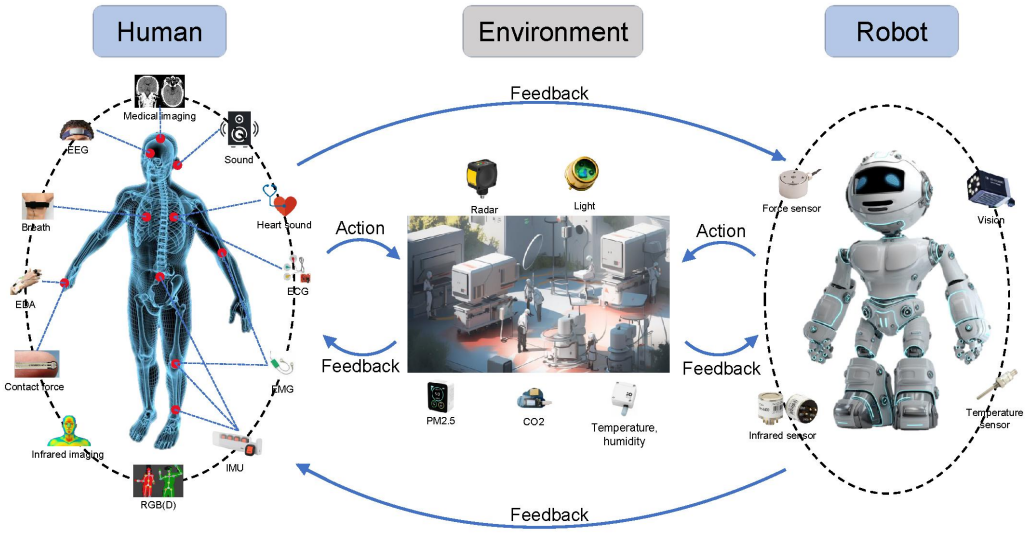


Figure 1. Schematic diagram of embodied intelligence driven human-robot interaction system.

significant data. Therefore, integrating advanced 5G communication is crucial to improving the effectiveness and efficiency of these systems.

Artificial Intelligence (AI): In the advancing field of AI neural networks, several large, general-purpose AI models like Chat-GPT have emerged. These models, trained on extensive text and image datasets, continuously learn and self-optimize, adapting to new data and challenges. Their strong generalization abilities make them suitable for tasks like semantic understanding and decision-making in HRI. However, integrating these models into HRI systems or customizing them for HRI applications still needs further exploration.

B. Application

In light of the previously discussed technological challenges, the subsequent section will delve into examples of HRI applications across various typical societal sectors.

Healthcare and Elderly Care: Healthcare is advancing with assistive robots that improve patient care by monitoring health, aiding rehabilitation, and offering companionship. Additionally, AI-powered surgical robots are being developed to perform intricate procedures more precisely and less invasively, marking a significant leap in medical technology and treatment efficacy.

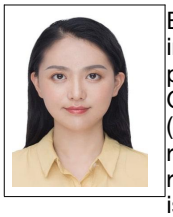
Manufacturing and Agriculture: Automation in various sectors is enhancing safety and efficiency by taking over repetitive and hazardous tasks. The integration of AI and robotics is improving quality control and production adaptability. Additionally, robots equipped with AI and environmental sensing are set to transform farming practices, optimizing everything from planting to harvesting.

Service and daily life: The deployment of robots in retail, hospitality, and customer service, powered by AI language models, is enhancing user experiences through personalized interactions. Additionally, domestic robots are revolutionizing household chores, offering convenience and saving time. Personal assistant robots, also AI-driven, are providing organizational support, reminders, and companionship, streamlining daily life.

Public Safety and Security: Robots designed for surveillance and emergency response are now capable of operating in hazardous environments, greatly enhancing safety measures. Additionally, the use of AI-driven analysis is revolutionizing threat detection and public safety monitoring, making these processes more efficient and effective.

IV. Opportunity

The advancement of HRI brings forth a wealth of opportunities, spanning various sectors. It not only improves work efficiency and quality but also leads to innovative service methods and business models. This boosts productivity and resource efficiency across different industries. Actively adopting and integrating HRI technology is key to shaping the future of these sectors, with its influence extending to strengthening the global supply chain's resilience and adaptability. Moreover, the widespread implementation of HRI could spur innovation and enhance competitiveness, potentially leading to the emergence of new markets and industries, thereby influencing the global economic landscape.



WEN QI received her Ph.D. degree in Bioengineering from Politecnico di Milano, Italy, in 2020. She strongly collaborates with prestigious universities in Italy, the Netherlands, Germany, UK, Japan, New Zealand, USA. She (co-)authored over 40 publications in peer-reviewed journals and conference proceedings, receiving about 1100 citations (h-index 18). She is also the permanent ICRA/IROS/ICARM reviewer and the Guest Associate Editor for a few journals, such as JBHI/TII/RAL/T-ASE/NN/EAAI.

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