Wang *et al. Intell Robot* 2024;4:196-9
DOI: 10.20517/ir.2024.12

Intelligence & Robotics

Editorial

Open Access

Check for updates

Embracing the future: the rise of humanoid robots and embodied AI

Jiankun Wang[1,2], Chaoqun Wang[3], Weinan Chen[4], Qi Dou[5], Wenzheng Chi[6]

[1]Shenzhen Key Laboratory of Robotics Perception and Intelligence, and the Department of Electronic and Electrical Engineering, Southern University of Science and Technology, Shenzhen 518055, Guangdong, China.
[2]Jiaxing Research Institute, Southern University of Science and Technology, Jiaxing 314050, Zhejiang, China.
[3]School of Control Science and Engineering, Shandong University, Jinan 250100, Shandong, China.
[4]School of Electromechanical Engineering, Guangdong University of Technology, Guangzhou 510006, Guangdong, China.
[5]Department of Computer Science and Engineering, The Chinese University of Hong Kong, Hong Kong 999077, China.
[6]Robotics and Microsystems Center, School of Mechanical and Electric Engineering, Soochow University, Suzhou 215006, Jiangsu, China.

Correspondence to: Prof. Jiankun Wang, Shenzhen Key Laboratory of Robotics Perception and Intelligence, and the Department of Electronic and Electrical Engineering, Southern University of Science and Technology, 1088 Xueyuan Avenue, Shenzhen 518055, Guangdong, China. E-mail: wangjk@sustech.edu.cn

How to cite this article: Wang J, Wang C, Chen W, Dou Q, Chi W. Embracing the future: the rise of humanoid robots and embodied AI. *Intell Robot* 2024;4:196-9. https://dx.doi.org/10.20517/ir.2024.12

Received: 11 May 2024 **Accepted:** 14 May 2024 **Published:** 20 May 2024

Academic Editor: Simon X. Yang **Copy Editor:** Pei-Yun Wang **Production Editor:** Pei-Yun Wang

1. OVERVIEW

In an era characterized by rapid technological advancements, humanoid robots and embodied artificial intelligence (AI) stand out as frontiers pushing the boundaries of what machines can achieve. Humanoid robots, intelligent embodiments designed to resemble and mimic human behavior, have the potential to revolutionize various areas, from healthcare to industry and beyond. Equipped with advanced sensors, actuators, and AI algorithms, these robots can perform tasks with precision and efficiency, freeing humans from mundane or dangerous activities, offering personalized assistance to individuals with disabilities, and providing companionship and aiding in therapy sessions. In a broad context, they cut across many disciplines, such as mechanical engineering, control engineering, AI, and cognitive science. These technologies, which merge the digital intellect of AI with physical embodiments, are not just the products of scientific endeavor but are also becoming integral to addressing complex societal challenges and keys to the potential future they promise.

2. CHALLENGES AND OPPORTUNITIES

The development of humanoid robots involves intricate technological innovations. These robots are not only about artificial limbs and walking mechanisms; they incorporate advanced AI technologies to perceive the world, make decisions, and interact with humans. However, the road to sophisticated humanoid robots is fraught with challenges.

2.1 Mechanical dexterity

Humanoid robots offer the opportunity to replicate human-like movements and dexterity, enabling them to perform a wide range of tasks with precision and agility. However, achieving full mobility and dexterity comparable to humans remains a challenging task due to the complex nature of human biomechanics. Developing advanced actuators, such as servo motors and pneumatic muscles, will allow for fluid and natural movements, making humanoid robots well-suited for tasks requiring fine motor skills.

2.2 Complexity of motion control

Achieving human-like movements in humanoid robots poses significant challenges in motion control and coordination. Coordinating multiple actuators and joints to replicate natural movements requires sophisticated control algorithms and feedback mechanisms to ensure stability and efficiency.

2.3 Sensing capabilities

Humanoid robots need to be equipped with an array of sensors that enable them to perceive and interact with their surroundings. From cameras and light detection and ranging (LIDAR) sensors for visual perception to gyroscopes and accelerometers for balance and orientation, these sensors provide valuable feedback for navigation, manipulation, and interaction with humans and other robots. Integrating diverse sensors and processing data from multiple sources present challenges in sensor fusion and data interpretation. Ensuring consistency and accuracy in sensor readings requires robust sensor calibration, fusion, and filtering.

2.4 Adaptability of algorithms

While advances in AI algorithms have enabled humanoid robots to understand environments and interpret human cues to a certain level, developing robots that can fully understand and appropriately respond to a wide range of environmental contexts and human intentions is extremely challenging. Heavy reliance on pre-scripted programs and the inability to adapt to dynamic and unstructured environments remains an unresolved problem.

2.5 Cost and scalability

Developing humanoid robots with advanced mechanics and sensing capabilities entails significant costs regarding research, development, and manufacturing. Achieving scalability and affordability while maintaining performance and reliability continues to be a challenge, limiting the widespread adoption of humanoid robots in commercial and consumer markets.

3. FUTURE DIRECTIONS

The future of humanoid robots holds tremendous promise. We identify future directions from the perspectives of mechanics, sensing, control, algorithm, and cost.

3.1 Mechanics

Future humanoid robots may see advancements in material science and biomechanics. Lightweight and durable materials, such as carbon fiber composites and shape-memory alloys, will enable the development of more robust and agile robots. Additionally, bio-inspired designs, mimicking the structure and functionality of human musculoskeletal systems, will enhance dexterity and efficiency in movement. Modular designs will facilitate easy maintenance and customization, allowing for rapid prototyping and iteration of robot designs to meet specific application requirements.

3.2 Sensing

The future of humanoid robots will be characterized by advancements in sensing technologies, enabling them to perceive and interact with their environment more effectively. Multi-modal sensor arrays, combining vision, touch, and other sensing modalities, will provide robots with a comprehensive understanding of their surroundings. Furthermore, developments in sensor miniaturization and integration will reduce the size and weight of sensor systems, enhancing the mobility and versatility of humanoid robots.

3.3 Control

Future humanoid robots will leverage advanced control algorithms to achieve greater autonomy and adaptability. Using model-based control techniques, such as predictive modeling and optimal control, robots can anticipate and respond to dynamic changes in their environments. Reinforcement learning algorithms will enable robots to learn and refine their behaviors through interaction with the environment, allowing for more robust and flexible adaptation to diverse tasks and scenarios. Decentralized control architectures will facilitate distributed coordination among multiple robot modules, enhancing fault tolerance and scalability in complex systems.

3.4 Algorithm

From an algorithmic perspective, future humanoid robots will benefit from advancements in machine learning, computer vision, and natural language processing. Semantic understanding and context-aware reasoning will empower robots to infer user intention and respond intelligently to commands and queries. Furthermore, developments in planning and decision-making algorithms will make them autonomously generate and execute complex action sequences, performing a wide range of tasks with minimal human supervision.

3.5 Cost

As with any emerging technology, cost reduction will be a key focus for the future development of humanoid robots. Advances in manufacturing processes, such as additive manufacturing and robotic assembly, will reduce production costs for robot components. Standardization of robot hardware and software interfaces will enable interoperability and modularity, reducing development costs and facilitating technology transfer between research and industry.

4. CONCLUSION

Looking ahead, the evolution of humanoid robots and embodied AI offers a remarkable opportunity to enhance human capabilities and address challenges that were once insurmountable. Yet, the journey is as much about building our technological future as it is about understanding what it means to be human in an age of increasingly intelligent machines.

DECLARATIONS

Authors' contributions

Substantial contributions to conception and design of the study: Wang J, Wang C, Chen W, Dou Q, Chi W
Original draft: Wang J, Chi W

Availability of data and materials
Not applicable.

Financial support and sponsorship
This work was supported by the Shenzhen Science and Technology Program under Grant RCBS20221008093305007, Grant 20231115141459001 and Young Elite Scientists Sponsorship Program by CAST under Grant 2023QNRC001.

Conflicts of interest
Wang J is an Editorial Board Member of the journal *Intelligence & Robotics*, while other authors have declared that they have no conflicts of interest.

Ethical approval and consent to participate
Not applicable.

Consent for publication
Not applicable.