Outcomes of World Internet Conference
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# Applications and Development Prospects of Humanoid Robots


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# Preamble

Humanoid robots represent a pivotal development in the integration of artificial intelligence and the physical world, serving as a critical vehicle for intelligent technology to transcend its virtual confines. By overcoming the limitations of traditional AI's "disembodied cognition," the unique humanoid form allows intelligent systems to adapt seamlessly to human work and living environments. This enables them to skillfully operate tools and equipment designed for people, marking a fundamental leap from mere information processing to versatile physical interaction. Consequently, the humanoid form provides AI with an optimal embodiment for understanding and reshaping the physical realm, thereby achieving a true "unity of knowledge and action." This report will examine the latest trends and future trajectory of the humanoid robot industry, offering profound insights into the applications and landscape of this technology. Our objective is to contribute to the sophisticated and high-quality advancement of the field.

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# I. New Development Trend of Humanoid Robot

Humanoid robots, a revolutionary breakthrough that integrates advanced technologies such as artificial intelligence and high-end manufacturing, are reshaping the global technological competitive landscape through disruptive innovation. They accelerate the formation of new productive forces driven by digital-physical integration, catalyze the emergence of new production relations based on human-machine collaboration, and serve as the core engine driving digital economies toward an autonomous economy, providing enhanced resilience for their sustainable development.

## (I) The development status of humanoid robots

### 1. What Is Humanoid Robot

A humanoid robot is a type of robot engineered with artificial intelligence and robotics technology, specifically designed to mimic human appearance and behavior. Drawing inspiration from the human body, these robots integrate principles of bionics and electromechanical control. What truly sets humanoid robots apart from conventional robots is their advanced, human-like intelligence. Empowered by large AI models, they achieve human-level perceptive, decision-making, and control capabilities , marking a significant leap in robotic intelligence. Furthermore, humanoid robots are characterized by their human-like physical form, typically comprising a head, torso, and limbs. This enables them to simulate human actions like walking and grasping. This human-like morphology allows them to integrate into human society quickly, accomplish specific tasks, and exhibit strong versatility and adaptability.

Humanoid robots are primarily categorized into wheeled, legged, and general-purpose humanoid robots based on their structural and functional characteristics. Wheeled humanoid robots utilize wheel-based propulsion coupled with robotic arms and dexterous hands, which grant them enhanced mobility. Legged humanoid robots focus on leg movement capabilities, with their hands primarily used for balance. In contrast, general-purpose humanoid robots feature two legs, two arms, two hands, and various sensing and artificial intelligence functions. They possess a comprehensive software and hardware foundation, enabling them to adapt to diverse tasks in open environments.

Source: China Telecommunication Technology Labs “ Report on the Development of Humanoid Robot Industry (2024) ”

## 2. Development of Humanoid Robot

**From 1950 to 1980,** during the infancy of the humanoid robot concept, Turing's papers proposed directions for AI, laying the theoretical foundation for robots. The prototype of modern robots was a pre-programmable robotic arm created by the Massachusetts Institute of Technology in 1954. General Motors first implemented the industrial robot Unimate on production lines for welding in 1960. Later, Stanford University developed the first mobile robot, and Waseda University created a humanoid robot capable of conversation.

**From 1980 to 2000,** the field underwent a period of early exploration. Thanks to breakthroughs in computer hardware and sensor technology, MIT launched the robot Kismet, which featured functions similar to those of human hearing, vision, and proprioception. In 1991, the six-legged robot Genghis appeared, capable of autonomous walking.

**From 200 to 2010,**during the stage of interdisciplinary integration and technology accumulation, humanoid robot research began to incorporate methods and technologies from diverse fields, including mechanism science, machine learning, and robotics. This period essentially marked the emergence of humanoid robotics as a distinct disciplinary branch.

**From 2011 to 2020,**the field witnessed significant technological advancements. The rapid development of deep learning technology empowered the advancement of humanoid robots. During this period, numerous bionic and humanoid robots emerged, designed to help robots adapt to natural environments. Honda's upgraded ASIMO robot, for instance, demonstrated the ability to perform delicate tasks such as grasping objects and pouring liquids. Similarly, Boston Dynamics' Atlas showcased remarkable capabilities, not only walking, running, and jumping in complex outdoor environments but also maintaining exceptional balance across diverse terrains, including snow-covered surfaces and grasslands.

**From 2022 to now,**the industrial applications of humanoid robots are gaining significant popularity. Large language models (LLMs), exemplified by ChatGPT, have immense potential for humanoid robots in terms of intelligent perception, autonomous decision-making, and even human-like interaction, progressively transitioning them into practical industrial applications. Leading companies and emerging "unicorns" such as Unitree, UBTech, Figure, Optimus, and Boston Dynamics have been instrumental in driving the deep integration of humanoid robots into production practices. These companies are pushing the boundaries of what humanoid robots can achieve in real-world scenarios.

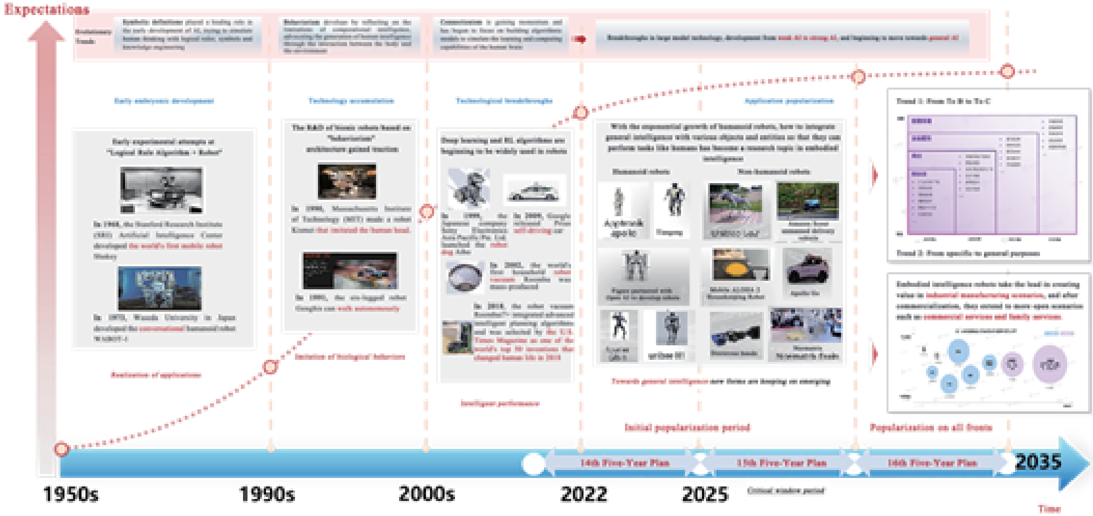


Figure 2 Development History and Outlook of Humanoid Robot

(Source: China Unicom Research Institute)

## (II) Broad Prospect in the Global Humanoid Robot Market

### 1. Different Focuses on the Strategic Layout of Embodied Intelligence in Various Countries

**Major economies worldwide attach great importance to the development of humanoid robots. There are profound strategic considerations and multiple driving factors behind it. The United States** is focusing on basic research in humanoid robots, while maintaining its leading position. The National Robotics Initiative 3.0, Data, Analytics, and Artificial Intelligence Adoption Strategy released by the Department of Defense, and Governing AI for Humanity: Final Report have been released successively. Furthermore, the Department of Defense has actively launched robotics challenges to incentivize innovation and attract the world's top research teams, directly fostering advancements in crucial areas of humanoid robot development.

**China** is offering strong policy support for the development of humanoid robots. In January 2023, the Implementation Plan for the "Robot Plus" Application Action, jointly issued by China's Ministry of Industry and Information Technology and seventeen other ministries, set explicit goals for robot development for the first time. These goals include realizing over 100 new robot application technologies and solutions and promoting more than 200 typical robot application scenarios. Subsequently, the Guiding Opinions on Innovative Development of Humanoid Robots was issued. This document specifically focuses on the key frontier of humanoid robotics, clarifying essential development directions. These include strengthening the forward-looking development of basic standards and building a comprehensive innovation system for humanoid robots.

**EU** is actively advancing the development of embodied intelligence, with a focus on its safety and transparency. It successively launched the EU Robotics R&D Plan and European Approach to Artificial Intelligence. Through research initiatives like Horizon 2020, these frameworks have supported collaborative research among European countries in the field of humanoid robotics.

**Japan** is integrating robots into society and making them a key part of its social foundation. In 2022, the Japanese government increased its financial support to 105.7 billion yen for robot-enabled application scenarios in manufacturing, services, and medical services. Against the backdrop of an aging society, the replacement of manpower by robots is a key support area. **South Korean** Ministry of Science and ICT has formulated the "Robot Future Strategy 2022", clarifying its focus on humanoid robots as a key development priority, and plans to allocate substantial funding for R&D initiatives and talent cultivation in related technologies.

## 2. Rapid Development of the Global Humanoid Robot Market

The next period will witness rapid growth in the market size of Humanoid Robots. In terms of the overall scale, China Gaogong Robot Industry Research Institute (GGII) predicts that the global market sales of humanoid robots are expected to reach 12,400 units in 2025, with a market size of 6.339 billion yuan. By 2030, global market sales will reach nearly 340,000 units, with a market size exceeding 64 billion yuan. By 2035, sales will exceed 5 million units, accompanied by a market size exceeding 400 billion yuan . According to Goldman Sachs' prediction, the global humanoid robot market is expected to reach 154 billion USD by 2035 .

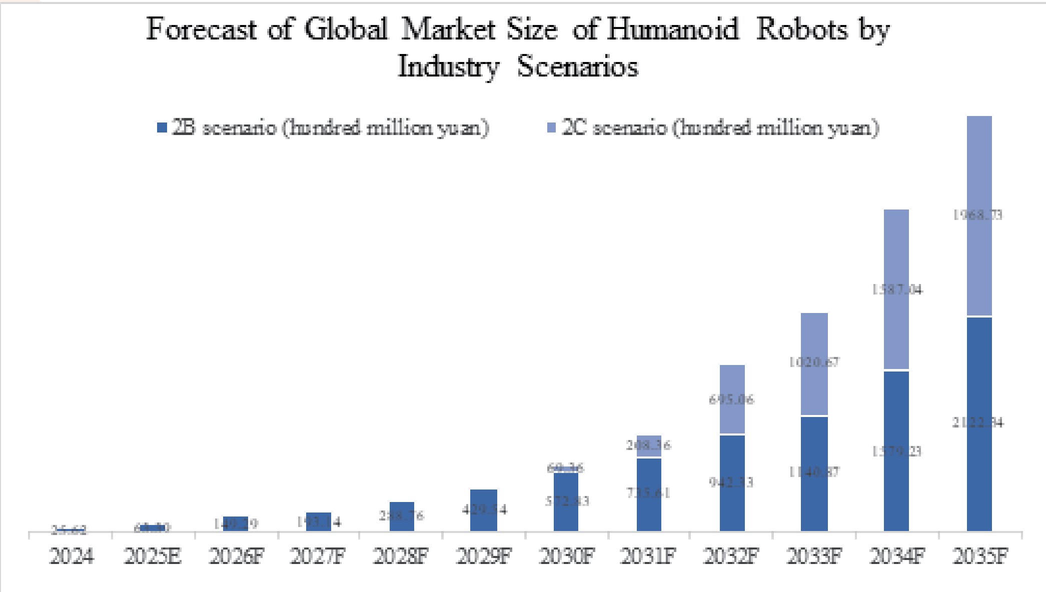


Figure 3 Global Market Size and Outlook of Humanoid Robots

(Source: Gaogong Robot Industry Research Institute)

**In terms of investment and financing,** data from CB Insights shows the humanoid robot market reached a record 1.2 billion in funding in 2024, with projections indicating it will achieve 2.3 billion this year, marking a doubling of capital inflows.


Figure 5 Overview of Foreign Company Financing

(Source: China Unicom Research Institute)

## 3. Accelerated Implementation of Humanoid Robots by Technology Giants from Various Countries

Overall, humanoid robotics products around the world have all entered the product launch and application verification stage; however, there is still a long way to go before commercialization and mass production on a large scale.

Global technology giants have announced the launch of multiple humanoid robots. **Tesla,** Inc. released the humanoid robot Optimus Gen 2. In June 2024, Optimus Gen 2 had been used in Tesla's factory for battery sorting training. **Boston Dynamics** released the humanoid robot Atlas, which has also been used in car factories to perform such tasks as moving car pillars. **Agility Robotics** released the humanoid robot Digit. Digit can complete daily warehouse work such as handling goods, palletizing, and unloading, and has been applied in GXO and Amazon. The unicorn company **Figure AI** empowers humanoid robots through the OpenAI large model and launches the robot Figure 02, which can complete complex tasks such as folding clothes, cleaning tables, and packing shopping bags. It has also been tested in BMW car factories for parts assembly and other tasks. **UBTECH** has launched the Alpha and Walker series robots. With its core customers and business scenarios tailored for education, logistics, retail, and other industries, it is the humanoid robot company that has developed cooperation with the most significant number of car manufacturers worldwide.

# II. The Technological Evolution of Humanoid Robots

## (I) Continuous Advancement in the Intelligent Perception and Decision-Making of Complete Robots

Source: China Gaogong Robot Industry Research Institute " Blue Book on Humanoid Robot Industry Development in 2025"

Source: Goldman Sachs "Humanoid Robots: Sooner Than You Might Think"

Source: CICC, "Embodied Intelligence: AI's Next Stop"

In the global humanoid robot sector, Tesla, Figure AI, and Boston Dynamics represent the top tier of innovators, with European and American companies such as 1X and Digit also making significant strides. These firms are pursuing lightweight designs and high degrees of freedom in their hardware while leveraging large AI models in their software to enable multimodal perception and reasoning. Several of these products have already entered scenario-based testing, demonstrating the potential of humanoid robots in diverse applications, including industrial production, public services, and special operations. It is anticipated that 2025 will mark the inaugural year for the mass production of humanoid robots.

Tesla's Optimus series has demonstrated a capacity for rapid iteration. The Optimus Gen-1, released in October 2022, stands 173 cm tall, weighs 73 kg, and is equipped with an automotive-grade Full Self-Driving (FSD) system. It features 28 degrees of freedom in its body and 11 in its hands, enabling basic movements. In 2023, the Gen-2 model achieved a significant breakthrough; its weight was reduced to 63 kg, and its walking speed increased by 30%. The addition of neck articulation markedly improved its balance, allowing it to navigate uneven terrain such as stairs. Its dexterous hands, fitted with tactile sensors, can precisely grasp fragile objects like eggs. The series is planned for mass production in 2026 at a price point of $20,000 to $30,000, targeting applications in factories, logistics, and home services.

Boston Dynamics' Atlas, the industry benchmark for athletic capability, introduced a new electric version in 2024. This latest model features a three-fingered dexterous hand, can carry objects weighing up to 14 kg, and is capable of complex actions including walking, jumping, and climbing stairs. Its core technology, the Model Predictive Controller (MPC), is driving its evolution from performing pre-programmed actions to autonomous path planning. This controller enables Atlas to maintain exceptional stability on complex terrain, continuously pushing the boundaries of motion control and perception technology. Its primary application remains in scientific research and validation.

Unitree Robotics represents China's innovative force in the field. The H1, launched in 2023, is equipped with self-developed M107 joint motors. Its design, featuring five degrees of freedom per leg, allows it to maintain stability while carrying a 30 kg load or withstanding external impacts. A 3D LiDAR system provides 360° environmental perception. The forthcoming G1 model, expected in 2025, is engineered for a more lightweight design, with 23 to 43 joint motors supporting advanced maneuvers like single-leg hopping. Its three-fingered dexterous hand, combined with multiple sensors, is designed to adapt to complex terrains. Driven by the UnifoLM world model, its autonomous learning capabilities are aimed at rescue and human-robot collaboration applications.

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Source: "Global Trends in the Technological Evolution of Humanoid Robots." May 29, 2025. https://mp.weixin.qq.com/s?

## (II) Empowering the Robot's "Brain" with Multimodal Models and Algorithms

**Large Models as the Ideal Foundation for the Robot's "Brain".** The technology underpinning a humanoid robot's "brain" is centered on large models, which provide the foundation for task interaction, environmental perception, task planning, and decision control. This "brain" must possess four key capabilities: real-time interaction for task-level communication with humans; multimodal perception to integrate information from various senses; autonomous and reliable decision-making to deconstruct complex tasks; and emergent and generalization abilities, allowing it to perform tasks in novel environments.

**A Coexistence of Diverse Paths in the Evolution of Multimodal Large Model Technology.** From a technological standpoint, the robot "brain" based on large models is advancing toward end-to-end intelligence along four parallel paths. The first is the LLM+VFM fusion route, which is currently the most mature approach. Represented by Google's SayCan, this method aligns a value function of pre-trained skills with a large language model, breaking down user commands into an executable task chain to close the loop between interaction and planning. The second is the Visual-Language Model (VLM) route, which focuses on bridging the semantic gap between language and vision. An example is Tsinghua University's CoPa model, which leverages the common-sense knowledge of foundational models like GPT-4V to generate task-oriented grasping poses and motion plans. The third is the Visual-Language-Action Model (VLA) route, which adds a motion control layer to the VLM. A prominent example is Google's RT-H, which jointly trains language, vision, and action modules on multi-task datasets to learn adaptive action policies for solving trajectory decision problems. The fourth route, the multimodal large model, is poised to become the dominant direction in the future. An example is MultiPY from MIT and IBM, which fuses 3D environmental features like vision and touch, constructing an object-centric scene representation through multi-view correlation to achieve full-dimensional environmental perception and decision-making.

## (III) "Cerebellum" Model Iteration and Optimization for Human-like Motion Control

Source: Unitree Robotics Official Website. https://www.unitree.com/

**Approaches to "Cerebellum" Motion Control: Model-Based and Learning-Based Routes.** The motion control system, or "cerebellum," is key to achieving natural and fluid movements in humanoid robots. The approaches are mainly divided into two categories: model-based and learning-based. The former involves planning and control through the establishment of kinematic and dynamic models, utilizing algorithms such as Zero-Moment Point (ZMP) and hybrid zero dynamics. However, this method is complex and costly to develop. The latter leverages artificial intelligence, establishing policies through human demonstration (imitation learning) or autonomous exploration (reinforcement learning), which can reduce development difficulty and accelerate iteration. Each approach has distinct merits and demerits, and their combined progression propels the advancement of humanoid robot motion control technology.

**The "Cerebellum" is Evolving Toward Control Strategies Based on Reinforcement and Imitation Learning.** Traditional robot control methods are limited in their adaptability to dynamic and open environments due to their heavy reliance on precise dynamic models and expert prior knowledge. Although data-driven, learning-based control can optimize strategies through experience, its generalization ability and environmental robustness still require improvement. The introduction of large models has brought new breakthroughs to the "cerebellum" control of humanoid robots, driving a paradigm shift from model-driven to data-driven control.

Large models significantly enhance data utilization by integrating prior knowledge. For instance, Language Plan utilizes GPT-3 to interpret task descriptions as abstract action sequences, enhancing the generalization performance of hierarchical reinforcement learning agents through state-space embedding. Models like LOFT and T-EBM achieve an end-to-end mapping from language commands to control policies. In the domain of imitation learning, visual-language models are opening new pathways. CLIP-ASAP fuses CLIP's semantic encoding with causal language modeling to predict key action frames based on visual observations and language instructions, thereby supporting the long-horizon learning of complex skills. Current challenges are centered on three dimensions: real-time computational efficiency, robustness in extreme environments, and the interpretability of decisions. Breakthroughs in multi-module collaboration are urgently needed to realize a truly end-to-end autonomous system.

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Source: China Academy of Information and Communications Technology (CAICT), "Research Report on the Development of the Humanoid Robot Industry"
Source: Embodied Intelligence and Humanoid Robot Forum. June 7, 2025. https://event.baai.ac.cn/activities/898

## (IV) The "Limbs": Components of the Robot's Physical Form

The "limbs" of a humanoid robot are crucial for executing human-like functions and are composed of advanced technologies such as chips, sensors, and actuators (including motors and dexterous hands). These technologies work in concert to provide the robot with human-like motor skills and interactive capabilities, forming the physical foundation for it to perform tasks and adapt to its environment.

**Chips serve as the computational core of a humanoid robot's intelligence.** In terms of architectural innovation, global companies are actively exploring several avenues. In-memory computing architecture overcomes the "memory wall" to alleviate data transfer bottlenecks; neuromorphic chips mimic the operational patterns of human neurons to achieve low-power, dynamic processing; and heterogeneous computing integrates the strengths of CPUs, GPUs, and ASICs to enhance computational efficiency. Breakthroughs continue in manufacturing processes and packaging technology. The mass production of TSMC's 3nm process has significantly boosted chip performance. Chiplet technology is now widely used internationally, reducing cost and design complexity through chip stacking. Algorithm-hardware co-design has become a key trend, with the Transformer architecture driving the development of specialized accelerators, such as the LPU launched by Groq, which accelerates AI model computation.

**The fusion of multimodal sensors endows humanoid robots with sophisticated perceptual capabilities.** In the visual domain, 3D vision sensors have become a primary focus. While Tesla adheres to a pure-vision approach, companies like Boston Dynamics combine LiDAR with depth cameras to enhance the precision of environmental modeling. In the realm of tactile and force sensors, breakthroughs in the application of flexible tactile sensors have enabled Optimus Gen-2 to grasp an egg. Six-axis force sensors are widely used internationally to facilitate precise force control. Furthermore, multimodal fusion technology is on the rise; the RoboFusion system developed by MIT integrates data from vision, touch, and force sensors with reinforcement learning to dramatically improve the accuracy of industrial assembly tasks.

**As the core actuating components of humanoid robots, motors are continuously being upgraded.** Regarding control precision, servo motors from companies like Japan's Yaskawa achieve nanometer-level positioning and microsecond-level response times by optimizing drivers and encoders. Frameless direct-drive technology has revolutionized transmission methods, with products from brands like Switzerland's Maxon achieving over 90% energy conversion efficiency while reducing mechanical losses. Significant progress has been made in creating lightweight and high-power-density designs. Germany's FAULHABER utilizes carbon fiber materials and topological optimization to reduce motor volume by 20–30% and achieve a power density exceeding 1.5 kW/kg, meeting the demand for compact power sources in humanoid robots.

**The technology of dexterous hands for humanoid robots has advanced rapidly, with significant breakthroughs in degrees of freedom, perceptual capabilities, and material applications.** In terms of degrees of freedom, the articulation of these hands is constantly increasing. The dexterous hand of Tesla's Optimus Gen-3, for example, has been upgraded to 22 degrees of freedom, enabling it to accurately replicate complex human hand movements. In perception, the application of tactile sensors allows the hand to discern an object's shape, hardness, and texture, facilitating the fine manipulation of fragile items. Concurrently, advances in materials science are making dexterous hands lighter and more durable. The synergistic development of these technologies has greatly enhanced the robot's ability to perform delicate operations and interact with its environment, laying a solid foundation for the expanded application of humanoid robots across multiple scenarios.

## III. Global Humanoid Robots: Typical Practices and Explorations

In recent years, humanoid robots have been integrating into the core scenarios of human production and daily life at a pace exceeding expectations. Two key factors drive this acceleration: first, the leapfrog breakthroughs in foundational technologies such as artificial intelligence and the Internet of Things; second, the feasibility of large-scale applications enabled by declining hardware costs and improving algorithm efficiency. From a technical perspective, the evolution of deep learning frameworks has significantly enhanced real-time processing capabilities for multimodal data. For instance, models based on the Transformer architecture enable robots to simultaneously parse visual, auditory, and environmental feedback information, thereby efficiently executing the "perception-decision-action" loop in dynamic scenarios. From a cost perspective, the miniaturization and reduced cost of high-precision sensors and biomimetic joint actuators have transformed humanoid robots from "luxury items" to more "accessible" products. This significantly shortens the product conversion cycle and establishes the economic foundation for large-scale application scenarios.

### (I) Humanoid Robots Pioneering the Reconstruction of Human-Machine Collaboration Paradigms in Industrial Manufacturing

In the industrial sector, humanoid robots, by deeply integrating perception, decision-making, and execution capabilities, are gradually becoming a core force driving the upgrade towards intelligent manufacturing. As industrial automation and intelligence advance, enterprises demand higher adaptability and flexibility from robots operating in complex environments. Currently, robot applications in industry are forming a progressive model: "single-point breakthroughs - production line coordination - factory-wide intelligence." Its development will go through three stages: initially coexisting with humans in the same production environment, focusing on solving human-robot collaboration issues; mid-term achieving more efficient and intelligent human-robot cooperation, yet still subordinate to human operation; long-term achieving the ability to perform tasks independently, with humans gradually withdrawing from the production frontlines, making "unmanned factories" a reality.

## 1. Typical Scenarios and Outcomes

Industrial manufacturing scenarios are the primary domain for initial implementation and are expected to become a critical core of new industrialization, supporting the intelligent upgrade of the manufacturing industry. Currently, humanoid robots have achieved successful applications in areas such as intelligent inspection, flexible manufacturing, and precision assembly.

**In intelligent inspection scenarios,** leveraging multi-robot collaboration and distributed intelligent systems, robots can optimize task allocation and path planning. For example, equipped with infrared night vision capabilities, they monitor temperature and humidity between equipment, identify personnel intrusions, provide leak detection warnings, and support multi-terminal remote management. Multiple robots work collaboratively to cover areas such as factory workshops. **In manufacturing and assembly scenarios,**products like automobiles and electronics have complex internal structures with numerous components. Robots, utilizing high-precision robotic arms and dexterous hands, can perform precise operations such as grasping, placing, and assembling. Tasks include loading/unloading, material handling, circuit board welding, screen installation, and battery installation. For instance, Foxconn collaborated with UBTech to jointly develop humanoid robots for precision electronic assembly lines, exploring micro-operation scenarios such as high-precision screw tightening and component placement.

## 2. Future Development Trends

**In terms of technology,** industrial humanoid robots will evolve from single-unit operation to "robot teams," achieving swarm intelligence collaboration and supporting "one-brain-multiple-machine" scheduling.

**In terms of applications,** although humanoid robots have achieved some relatively mature applications in industrial manufacturing, scaling into broader industrial scenarios requires adaptation time. The reliability requirements of industrial settings and enterprises' cost control are significant constraints on large-scale deployment. Humanoid robots will initially operate in structured scenarios with slower rhythms, such as industrial inspection, loading/unloading, material cart pulling, quality inspection, and handling. Future deployments in actual factory environments will involve continuously collecting and utilizing real-world data to optimize their intelligence and performance. Through the "data feedback loop" effect, they will progressively achieve tasks requiring certain levels of precision and flexibility in industrial settings.

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Source: Industrial Frontier | Top 10 Development Trends in Humanoid Robotics Industry for 2025. June 13,2025. https://mp.weixin.qq.com/s?__biz=MzUyMDc0MzI5Mw==&mid=2247522701&idx=1&sn=4b98371043e2271d25c45c715d0b354d&chksm=f87ce79d479e4ae68f30267be20c24e2332af3a0f6196c404d1c387d7dcf1bfd

Source: From 'Performance' to 'Work'—How Far Are Humanoid Robots from 'Factory Work'? | New Era of Robotics Business. June 18, 2025. https://news.qq.com/rain/a/20250618A08EX000

## (II) Humanoid Robots Exploring an Inclusive, Precise, and Caring Medical Future

The exploration of humanoid robots in the medical field is rapidly moving from laboratories to clinical practice. Their core value lies in combining human-like flexibility, AI decision-making capabilities, and multimodal interaction technologies to address medical resource shortages, enhance diagnostic and therapeutic precision, and improve personalized service levels. Since 2023, some general-purpose humanoid robots have also begun trials in medical settings. For example, Sanctuary AI in the US deployed its Phoenix humanoid robot in hospital environments to perform simple chores (delivering items, room disinfection); China's UBTech launched the "Cloud Sail" hospital guidance robot, which can guide patients and answer inquiries.

### 1. Typical Scenarios and Outcomes

Medical scenarios impose high demands on robots, requiring absolute safety and reliability, as well as gentle and friendly interaction.

**In clinical intervention scenarios,** humanoid robots play an assistive role in surgical procedures, enabling breakthroughs in technical precision and extreme collaboration. For instance, MIT's NanoSurgeon X1 system, equipped with atomic force microscope probes and quantum entanglement haptic sensors, can identify differences in cell membrane stiffness to facilitate early tumour boundary localization. **In nursing and companionship** scenarios,humanoid robots provide patients with comprehensive life support and emotional companionship. For example, socially assistive robots enhance the social skills of children with autism through interaction. Feeding robots, utilising perception and adaptive technologies, assist patients with tasks like eating and dressing, while providing real-time feedback and encouragement during rehabilitation exercises. For instance, CloudMinds' Cloud Ginger 2.0 recognizes over 100 emotional states through natural language interaction. Combined with a dopamine secretion prediction model, it dynamically adjusts lighting, music, and conversation content, reportedly reducing PHQ-9 depression scores by 14.3 points.

### 2. Future Development Trends

The future value of humanoid robots in healthcare extends beyond merely replacing human labour; it lies in expanding the boundaries of human capabilities, and enabling cellular-level diagnosis and treatment. Through advancements in computer vision, novel magnetically controlled materials, imaging tracking devices for micro-scale magnetic objects, as well as the development of visualized micro/nano manipulation techniques and magnetically controlled micro/nano swimming robots for targeted drug delivery within organisms, nanorobots will be able to perform intracellular targeted therapies. This includes tasks such as thrombus removal, drug delivery, and cancer treatment, paving the way for an inclusive, precise, and compassionate medical future.

## (III) Humanoid Robots Reshaping Productivity Paradigms in Transportation and Logistics

In the logistics and transportation sector, robots possess strong autonomous decision-making and learning capabilities, enabling them to adapt to more complex and diverse tasks. They are key factors expected to reduce circulation costs and help build an efficient, rapid, and intelligent logistics system. Current robot applications in logistics mainly include picking robots, forklift robots, material-handling robots, and tote-handling robots. The empowerment brought by humanoid robots can enhance work efficiency and management levels across various stages, including warehousing, loading/unloading, material handling, sorting, packaging, and delivery. For instance, Amazon recently tested Digit, a bipedal humanoid robot developed by Agility Robotics (a company it invested in), in its warehouse operations. Digit comprehensively performs tasks such as unloading trucks, moving boxes, and managing shelves, thereby significantly improving warehouse operational efficiency.

### 1. Typical Scenarios and Outcomes

**In flexible sorting scenarios,** traditional automation faces challenges in unstructured environments. Humanoid robots, equipped with LiDAR, cameras, and SLAM technology, will significantly enhance their environmental perception, route planning, and motion navigation capabilities. This enables them to better adapt to variable environments, identify multiple targets, autonomously adjust their paths, and promptly avoid obstacles, thereby empowering sorting and handling tasks in logistics. **In unmanned transportation scenarios,** robots achieve fully unmanned operation across the entire chain, from trunk line transportation to last-mile delivery. Operating 24/7 enhances logistics and delivery efficiency while reducing enterprise operating costs.

### 2. Future Development Trends

The future development trend of humanoid robots in logistics and transportation is shifting from technological exploration to large-scale deployment. Their core value lies in combining human-like flexibility and environmental adaptability to overcome the limitations of traditional automation equipment. The ultimate value of humanoid robots lies in reshaping the logistics productivity paradigm - breaking environmental constraints through "human-likeness," achieving seamless collaboration through "intelligence," and ultimately building zero-modification, fully adaptive, self-evolving logistics systems.

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Source: Zhiyuan Robotics Industry Research Institute. General Intelligence and Embodied Robots: Development Trends and Application Prospects. March 13, 2025. https://mp.weixin.qq.com/s/I_iQZDFR7oVUlKvCFtBZdA

Source: Trillion-Dollar Potential! Revolutionizing the Market! An In-Depth Analysis of Embodied AI's Application Prospects Across Industries - 2025 Edition. December 10, 2024. https://mp.weixin.qq.com/s/rUeh99v6WAa3pg7B8XJ6HA

## (IV) Humanoid Robots Reconstructing Efficiency and Experience in Home Life

In the home service domain, household service robots have evolved from initial vacuum cleaners to today's multifunctional robots capable of floor cleaning, object handling, and basic household chores. For example, 1X and OpenAI are deeply collaborating on developing EVE, an embodied intelligent humanoid robot. EVE can perceive and understand human daily working environments, learn, correct errors, and collect data during interaction to perform autonomous home and office assistant tasks. The application of humanoid robots in-home services is transitioning from conceptual exploration to practical implementation. Their core value lies in combining humanoid flexibility and emotional interaction capabilities to reconstruct the efficiency and experience of home life.

### 1. Typical Scenarios and Outcomes

**In household task execution scenarios,** robots demonstrate diverse functionalities. Using mobile bases for long-range operations in large spaces, they simulate human hands for tasks such as food preparation (chopping, stir-frying, plating), laundry, pet interaction, and watering plants. For instance, Norway's 1X Neo Gamma robot performs tasks such as vacuuming, window cleaning, and garment sorting, achieving fine grasping through its elastic motor-driven biomimetic hands. **In child companionship scenarios,** humanoid robots play a different role. Through gamified learning, they cultivate children's logical thinking and help establish learning habits. **In elderly care and emotional companionship scenarios,** humanoid robots provide health monitoring, emotional interaction, and daily life assistance. For example, the "Flying Swallow Robot", deployed in nursing homes, monitors elderly individuals' heart rate and blood pressure anomalies, provides medication reminders and emergency calls, thereby reducing accident risks.

### 2. Future Development Trends

In the future, humanoid robots will be able to perceive their surroundings in an anthropomorphic manner, utilise traditional tools, and autonomously execute tasks in uncertain environments, ultimately evolving into full-scenario home assistants. They will enter millions of households, much like cars, becoming indispensable life partners and helpers for every family, undertaking tasks such as rehabilitation assistance and household chores.

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Source: Logistics & Material Handling, Issue 10, 2024 (Click to View Mobile E-Journal).
Source: China Media Group | How Humanoid Robots Step into Real-World Application Scenarios, March 23, 2025. https://news.cctv.com/2025/03/23/ARTIX3ziNfTrV2GkS8epsQXr250323.shtml

**First, technological breakthroughs drive the expansion of scenarios.** The integration of multimodal large models and continuous learning technologies will enhance robots' adaptability in complex home environments, driving upgrades from single tasks (like cleaning, moving) to comprehensive services (such as health management, educational companionship). **Second, it will experience cost reduction and large-scale applications.** With supply chain maturation and breakthroughs in mass production technologies, the price of household robots is expected to decrease significantly, thereby accelerating consumer adoption. **Third, it moves toward ecosystem synergy and cross-border integration.** Home service robots will further integrate into ecosystems such as smart homes and healthcare, forming a full-chain value network encompassing "hardware + services + data."

Ultimately, household service robots will transform from "functional tools" into life partners that understand needs, offer warmth, and possess the capacity to evolve, reshaping the very definition of "home."

## IV. Explore New Paths for the Future Development of Humanoid Robots

### (I) Solidify the Hardware Foundation and Promote Interchangeable Standards in the Humanoid Robot Industry

At the hardware level, the primary challenges include durability, battery efficiency, and deep software integration. Future progress in this field will depend not only on technological breakthroughs and cost-effectiveness but also on establishing universal hardware and consistent standards.

**First, establishing unified hardware standards is essential. This will facilitate the sharing of universal dataset, enhance the reliability and interoperability of hardware maintenance, and help build global or regional collaborative networks.** Disparate technologies and fragmented standards currently hinder the advancement of humanoid robots. It is therefore crucial to define uniform hardware standards for robots in specialized fields by creating standardized interface protocols and modular architectures. This approach will simplify maintenance and extend equipment lifespan. Furthermore, developing modular hardware parameter benchmarks will improve interoperability between components. A standardized framework that unifies communication protocols and human-computer interaction norms will lower the cost of cross-platform collaboration, encourage data sharing among manufacturers, and foster an international network that spans R&D, manufacturing, and maintenance services.

**Second, supporting upstream component manufacturers is critical for driving breakthroughs in fundamental hardware technology and ensuring its widespread adoption.** Through cross-border cooperation, we can guide the development of these manufacturers, ensuring they can provide a stable supply of reliable components that integrate seamlessly with humanoid robot assemblers. **In the field of chips,** where application scenarios define hardware capabilities, the focus should be on overcoming the energy efficiency bottlenecks of heterogeneous computing architectures; co-optimizing algorithms and hardware can significantly reduce end-to-end latency. **In the field of sensors,** the emphasis should be on specialized applications, such as flexible tactile sensing and six-dimensional force control, alongside open protocol standards for fusing multi-modal perception data. **In the field of motors,** the key is to leverage supply chain integration to achieve an optimal balance of power density, control precision, and cost.

## (II) Enhance Perceptual Capabilities and Foster Integrated Innovation in Humanoid Robot Technology

The humanoid robot industry faces key challenges in core technology, data resource integration, and large-scale deployment. The omni-modal perceptual capabilities of these systems require significant advancement, while the high cost of quality data collection and discrepancies between simulated and real-world data limit improvements in model generalization. Moreover, the fragmentation of robot operating systems prevents the industry from achieving scale. To address these issues, a systematic approach is needed across technological synergy, data feedback loops, and platform ecosystems.

**The first is to build a deep collaborative ecosystem of industry, academia, and research, breaking through the bottlenecks of embodied intelligence, full-modal perception, and end-cloud collaboration technology.** To enhance perceptual capabilities, the focus must be on advancing end-to-end large models, as current versions lack sufficient depth in full-modality perception—spanning vision, touch, hearing, and smell—and have notable shortcomings in force and tactile feedback. Future efforts must concentrate on developing unified perception-decision-control frameworks through multi-modal data fusion. This involves utilizing neuro-symbolic systems to enhance the semantic alignment of multi-modal information and leveraging self-supervised learning to minimize dependency on annotated data. To address limited on-device computing power, it is essential to develop edge-side intelligent computing platforms and solve the communication latency inherent in edge-cloud synergy. Since compressing cabinet-level computing power into terminal devices remains a near-term challenge, edge-cloud collaborative computing emerges as the inevitable solution. In this model, the cloud manages complex model training and global knowledge updates, while the edge handles real-time perception and control.

**The second is to develop a virtual-real fusion training ground system and promote the deep integration of embodied intelligence simulation and real-world data.** To overcome high costs and data discrepancies, three paths can be pursued. One is to foster an international joint training system that integrates virtual and real environments. Using digital twin technology to build a collaborative virtual training ground enables all parties to construct high-quality, multi-modal corpora, thereby enhancing both the efficiency of data collection and the breadth of scenario coverage. Another path is to use industry alliances and cross-sector cooperation to build large-scale humanoid robot datasets, thereby advancing and refining the multi-modal data feedback loop. Open-sourcing these datasets can lower R&D costs, accelerate innovation, and attract more developers. Finally, integrating simulation with real-world data can create a "data flywheel" effect, where robots trained on simulation data are deployed into practical settings to collect interaction data, which is then used to iterate and improve their performance.

**The third is to build a platform ecosystem of universal development and network connection, breaking through the bottleneck of operating system fragmentation and enabling multi-machine collaborative scheduling.** The future of humanoid robot operating systems will center on generalization, collaboration, and scalability. Leading enterprises and research institutions should establish a general-purpose open platform and a technical open-source community. This would create a unified central control system for multi-robot scheduling, integrating a dual-core mechanism that combines large-model-driven task planning with data-driven, end-to-end skill execution. This system would provide standardized interfaces for robots of all brands and forms. Additionally, the participation of telecommunication operators, internet companies, and cloud vendors in building a networked platform for humanoid robots will unlock their potential for large-scale application, facilitating the management of thousands of devices.

## (III) Focuse on Key Scenarios and Drive the Sound Development of Humanoid Robot Applications

As a technology that deeply integrates artificial intelligence with the physical world, humanoid robots will not only boost manufacturing efficiency but also reshape entire industries.

**For industry applications, humanoid robots can follow a phased, differentiated development path. The initial focus should be on wheeled robots, which are less technically demanding, before progressing to fully humanoid robots.** Application scenarios should be approached with a tailored strategy, progressing from more straightforward to more complex tasks. Deployment should begin in key industries like automotive manufacturing and gradually expand into sectors such as semiconductor manufacturing and pharmaceuticals, where process-oriented work gives the technology a natural entry point. Industrial humanoid robots can significantly enhance the flexibility and adaptability of factory production. Within manufacturing, large-scale deployment should initially target processes like loading, material handling, and inspection. As the technology matures, their application can expand to more complex manufacturing processes.

**Finally, establishing an international collaborative mechanism for innovation is vital.** Regular technical seminars and technology-matching events can promote knowledge sharing and standards collaboration in core areas like embodied perception, human-robot interaction, and autonomous decision-making. This cooperation should focus on overcoming common technological hurdles, such as multi-modal data fusion and environmental self-adaptation. Research institutions, universities, tech companies, and government departments worldwide are encouraged to strengthen cooperation, share cutting-edge research, and jointly advance the global R&D and standardization of humanoid robot technology. At the same time, special international talent exchange programs are important for supporting researchers, engineers, and students in fields such as generative AI, thereby further promoting global exchange and the deep integration of technological innovation.