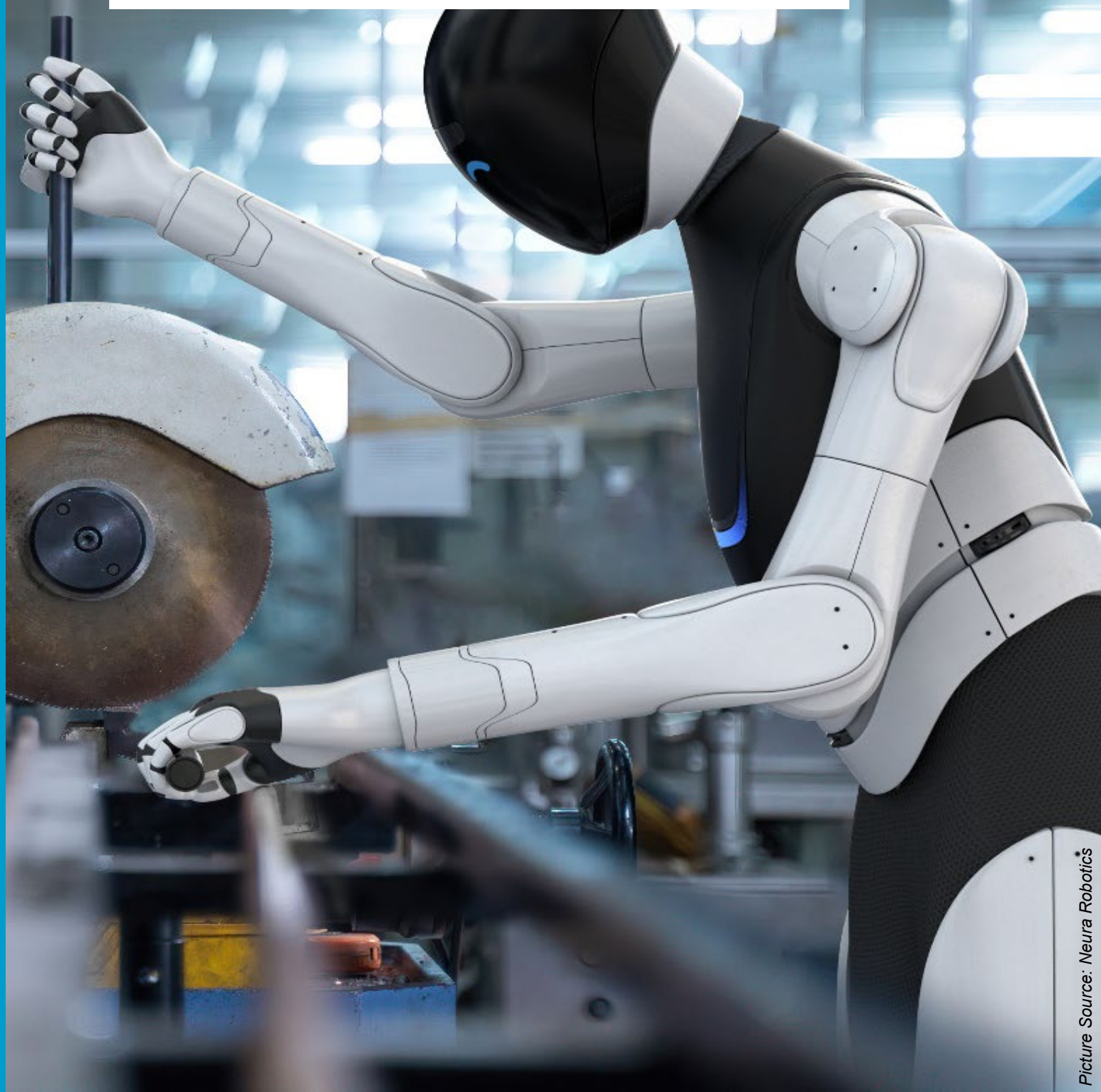


POSITION PAPER

Humanoid Robots

VISION AND REALITY



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EXECUTIVE SUMMARY & KEY FINDINGS

Hype about humanoid robots

People's interest has been fueled by futuristic scenarios involving humanoid robots in homes, businesses, and public spaces. This fascination has a cultural backdrop, as humanoids have long been a staple of science fiction, particularly in film. People are intrigued by the prospect of these fictional depictions becoming reality. Recent videos on social media showcasing the potential of AI-powered humanoids have further boosted this interest, suggesting an impending revolution in robotics.

Robots for human-centric environments

The objective behind constructing humanoid robots is to tackle tasks in human-centric environments and push the boundaries of robotics in both research and practical applications. The vision is to create a **general-purpose robot** that can perform not just one task, but many. The demand for a quick, universal helper to maintain manufacturing and services is evident given that most developed economies are experiencing persistent labor shortages and impending demographic shifts. To the extent that our environments are optimized for the human body, a general-purpose robot based on human motion mechanics and form factor could have an advantage. As technology evolves, these robots are expected to be increasingly used in fields ranging from **industrial use** and **service use**.

(Please find definitions in IN BRIEF).

Trends driving development

Significant technological breakthroughs have been made in recent years, including advances in AI, machine learning and improved core components, which have enhanced the capabilities of humanoids. In particular, generative AI has led to new methods by which humanoids acquire their capabilities. They can learn from demonstration and even figure out tasks independently. This could also transform the way traditional robots are programmed and

pave the way for new application scenarios of smart manufacturing.

(Please find more details in DEEP DIVE "Technological Trends").

US Tech and government invest

The idea of a revolution in robotics is reinforced by major tech companies such as NVIDIA, Tesla and Amazon, as well as private investors, announcing significant funding for humanoid robots. The support of a growing number of start-ups is also contributing to the current hype. Additionally, there is significant interest in their use for military and security purposes, resulting in substantial funding from DARPA and the US Department of Defense.

China promotes humanoid robots

At the same time, China - the world's largest market for industrial robots - published detailed goals for the country's ambitions to mass-produce humanoids. China's Ministry of Industry and Information Technology (MIIT) predicts humanoids are likely to become another disruptive technology, similar to computers or smartphones, that could transform the way we produce goods and the way humans live. China's initiative to promote humanoid robots as a cutting-edge technology is an important next step in integrating robotics with other emerging technologies.

(Please find more in DEEP DIVE - Humanoid adoption by region)



Figure 1: Gaps in labor supply are being filled by humanoids. Picture Source: iStock.com/Kinwun

IN BRIEF

What is a humanoid robot?

Intro

A **humanoid robot** is a robot that resembles the human body in shape. These robots are often designed for functional purposes. They usually have a torso, a head, two arms and two legs. Some only have the upper part of the body, and some are wheeled. As with any robot, some degree of autonomy is required. Typically, mobility is a crucial element in humanoid robots.

Definition

IFR proposes a definition of a humanoid robot that shall serve as a unified globally accepted discussion and the basis for standardization work:

A humanoid robot is a robot with a human-like aesthetic appearance (typically two arms with hands, two legs, torso and head) capable of performing tasks in an environment designed for humans without the need to adapt it.

Their task performance is enhanced by having human-like sensing abilities such as seeing,

hearing, touch sensing, interacting with humans and environments.

ISO 8373:2021 defines a humanoid robot as a robot with body, head and limbs, looking and moving like a human.

Humanoid robots for industrial use

Humanoid robots are evolving from research prototypes to practical machines that support industrial tasks. They are seen as a promising technology where flexibility is required, typically in environments designed for humans. Pioneered by the automotive industry, applications in warehousing and manufacturing are coming into focus worldwide.

Humanoid robots for service use

Unlike their industrial counterparts, humanoid robots for service-use often assume roles in hospitality, education, and public service by mimicking human expressions, gestures, and even emotions.

Many early applications in Asian countries e.g. China, South Korea and Japan currently target entertainment, hospitality and personal care purposes.



Figure 2: Humanoids designed to support industrial tasks. Picture Source: iStock.com/Thinkhubstudio

DEEP DIVE

Drivers of humanoid development

The field of humanoid robotics is expanding rapidly. Both researchers and companies are exploring improved human–robot interaction techniques, advanced sensor integration and adaptive AI systems that enable robots to learn and evolve within complex workflows. These advances are paving the way for new roles in a variety of customer industries and applications, many of which are already affected by a shortage of human labor.

Main industries and applications

Manufacturers, logistics operators, and service providers are emerging as the primary customers for humanoid robots:

In the **automotive industry** some companies are running commercial pilot projects with humanoids to test the readiness for work. Prototypes are being used for kitting (gather components for assembly), tending machines, and monitoring production processes.

Closely aligned are **logistics and warehousing** operations. The design of humanoid robots means they can navigate factory floors and warehouses originally built for human workers. This might in particular support brownfield automation in warehouses, reducing the need for custom-built robotic systems and specialized infrastructure.

With ongoing pilot projects in manufacturing and logistics, both start-up and established robotics companies find that these environments represent fertile ground for extending the capabilities of humanoid robots. Future applications will range from operating in complex machinery layouts in factories to tight warehouse corridors. They will free up human workers by taking over simple assembly tasks, manual quality testing and handling hazardous materials, as well as working in areas with poor sanitary conditions.

In addition to the industrial sector, customer-facing businesses such as **retail** and **hospitality** are beginning to experiment with humanoid robots as interactive service agents. Their conversational capabilities and human-

like appearance aim to bridge the gap between machine efficiency and the warmth of human interaction, transforming the customer experience in these sectors. Early trials in automated stores have seen humanoid robots managing inventory, processing payments, and providing product information. In the hospitality sector they are designed to perform tasks such as greeting guests, supporting the concierge, providing room service and assisting with wayfinding.



Figure 3: Fourier GR-1 being used in Shanghai International Medical Center for Rehabilitation. Picture Source: Fourier Intelligence

In **healthcare**, humanoid robots are being designed to support overburdened medical staff by handling routine tasks such as transporting equipment, lab assistance and even offering basic patient care. Several hospitals across Europe and Asia are already testing units equipped to perform physical therapy exercises and monitor vital signs, potentially reducing the risk of caregiver injury and alleviating the strain on aging workforces.

Humanoid robots are set to lend a helping hand in **people's homes** in the future. Experts foresee them undertaking tasks such as vacuuming, dusting and mopping floors or other domestic routines like tidying up. Alongside these physical tasks, some robots are being designed to act as digital companions, blending practical support with social interaction. Like smartphones and other consumer devices, these applications have the potential for mass adoption. Social and cultural factors, including how comfortable people feel with humanoids, will influence their adoption in everyday life.

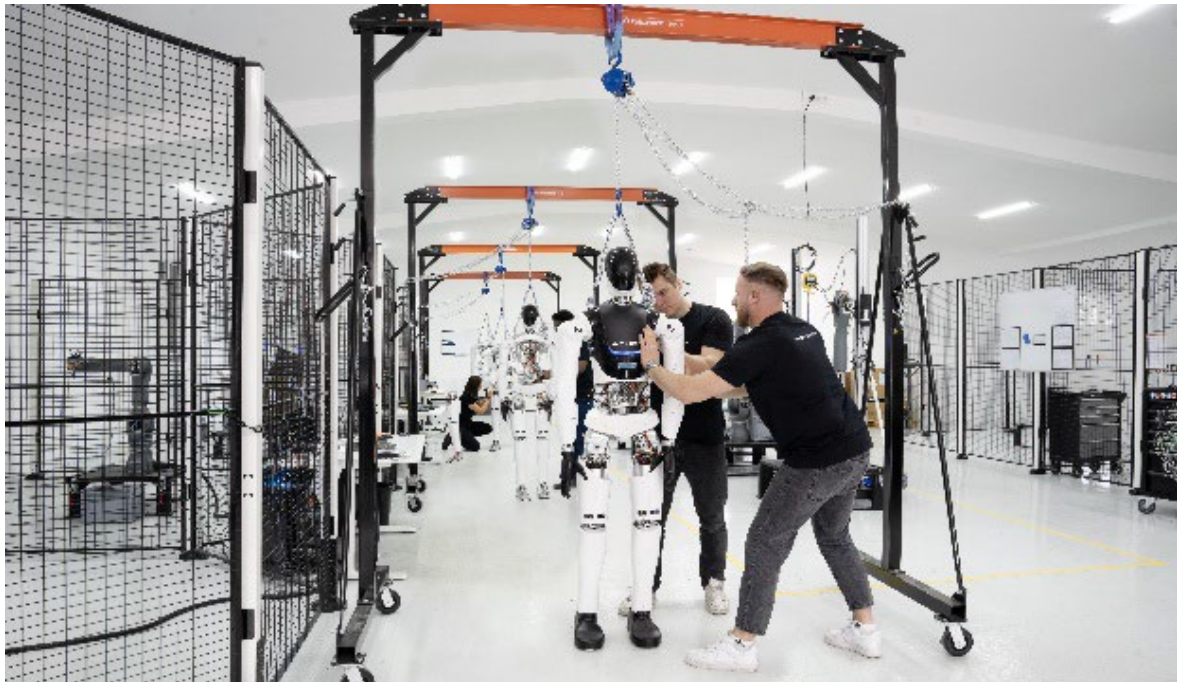


Figure 4: Humanoid production line. Picture Source: Neura Robotics

World regions with cultures that tend to embrace robotics will lead the race to a more widespread adoption. However, this is not expected to happen overnight, but rather within the next 20 to 30 years.

Technological Trends

As technological advances continue and operational confidence grows, the vision of a future in which humans and intelligent machines collaborate might become a reality.

The use of lighter, more durable **materials and miniaturized components** is enabling the creation of more agile, realistic humanoid robots. Adoption of **tactile sensors and force torque sensors** means that grippers and hands can now be more precise, mimicking human touch and dexterity. Thanks to new developments in **dynamic balancing, joint flexibility** and **motor control**, humanoids can now perform complex movements such as running, jumping and navigating uneven terrain. Safety enabling features such as **force feedback** and **compliance control** regulate movement to prevent harm during direct

human-robot interaction. Improved **SLAM technologies**¹ and **LIDAR systems**² as well as cameras and vision systems enable humanoids to navigate independently in complex environments, enhancing their usefulness in real-world applications.

Advanced AI and machine learning such as Vision Language Action Models (VLAMs) are enabling humanoids to learn from data, improve decision-making, and adapt to new environments, making humanoids more autonomous and capable. Lack of training data can be tackled by virtual learning environments with digital twins in simulation. Imitation learning enables humanoids to learn directly from observing humans. Advances in natural language processing and emotion recognition are making humanoid robots better at understanding and responding to human emotions, improving their utility in service roles.

Edge computing and processors specifically suited to complex inputs and AI algorithms reduce the latency for critical tasks, improving responsiveness and autonomy. The integration of humanoids with **cloud computing** allows for

¹ SLAM (Simultaneous Localization and Mapping) a technology used by robots to create a map of an unknown environment while simultaneously tracking their own position within that map.

² LIDAR (Light Detection and Ranging) is a remote sensing method that uses laser light to measure distances to an object or surface.

real-time data processing, remote control, and coordination between multiple robots, enhancing their functionality and scalability in industrial and service applications. Enhanced sensors for vision, touch, and hearing, coupled with more efficient actuators, are allowing humanoids to interact with their environment more naturally and precisely.

New developments in **battery technology** and **energy management** are extending the operational life of humanoid robots, making them more practical for long-term use.

Tradeoffs and limitations of humanoids

The comparison of humanoid robots with traditional industrial robots highlights important aspects of their limitations. Critics point to the 'form follows function' rule: the human body may not be suited to certain tasks. Traditional industrial robots tend to have fewer joints tailored to a specific task, such as welding or assembly. This results in simpler control schemes that are faster and more reliable than humanoid robots. As a result, industrial robots are likely to remain the backbone of high-speed, precision-driven manufacturing environments. In industrial production settings, tasks are repetitive and demand millimeter-level precision at high speeds. Industrial robots excel here—they perform highly specialized movements quickly and consistently. When the job calls for extreme specialization, dedicated industrial robots generally outperform their humanoid counterparts.

Humanoid robots offer a more general approach. They combine mobility with human-like interaction, making them suitable for service tasks. In such applications, humanoids may be more acceptable than traditional machines. This advantage can also be a risk: Their human-like appearance and behavior can create fear in people, leading to a general rejection of robotic technologies, known as the uncanny valley.

Compared to the wired, high-power solutions available for many traditional industrial robots, battery power is a fundamental challenge for humanoid robots. The battery life is typically only one hour today. It would need to be increased to at least four to five hours of

operation with one hour of fast charging, or a runtime of twenty hours.

Finally, while some humanoid robots have mastered mobility and agile movement, and others can handle cognitive and intellectual challenges, none can do both yet. Humanoids so far have not mastered many basic human-like capabilities, serving as general-purpose tools. Dedicated-purpose humanoids are much closer to deployment.



Figure 5: Humanoid with human-like interaction.
Picture Source: [iStock.com/Thinkhubstudio](https://www.iStock.com/Thinkhubstudio)

Humanoid adoption by region

The approach to humanoid robots varies significantly across regions like the Americas, Asia and Europe, reflecting differences in cultural attitudes, technological priorities, and economic goals.

In the **United States**, major tech companies like Google, Amazon and Tesla are heavily developing advanced AI and robotics technologies. Besides military funding, a lot of private investments support this development and result in a large number of start-ups developing humanoid robots. There is a strong interest in using humanoids in logistics, healthcare and manufacturing. Humanoid robots are seen as tools for enhancing productivity and efficiency rather than as social companions. The focus is more on practical applications and less on integrating robots into daily social life.

China put humanoids in the center of their national strategy. The government wants to showcase its competences and global competitiveness in this field of technology. There is a strong emphasis on using humanoids in the service sectors, such as



Figure 6: Humanoids perform a wide range of tasks in various environments. Picture Source: PAL Robotics

customer service. The use in manufacturing to automate production lines and reduce reliance on human labor seems only a second step. One key element of the Chinese strategy is to establish a supply chain for key components that is scalable.

Japan has been a leader in the development of humanoid robots since before other countries entered the field, with Honda's Asimo being an early example. Robots are regarded as companions rather than mere tools. Humanoid robots such as Pepper and Palro are designed primarily as social robots and are used in educational settings, commercial stores and elderly care facilities. This reflects the needs of Japan's ageing society. The focus is on creating robots that can live harmoniously with humans and are accepted as part of society. Leading companies such as Kawasaki are developing humanoid robots as research platforms.

Europe places a strong emphasis on the ethical implications of robotics and AI. Europe has a significant focus on collaborative robots that work alongside humans in industrial settings. The focus is on enhancing safety, efficiency, and human capabilities, rather than

on replacing human workers. The focus is on human-centric design and the social and societal impact of robots. European businesses are more cautious about the use of humanoids to meet the automation needs of the manufacturing and service sectors in the short to medium term.

All regions recognize the importance of AI in advancing humanoid robots, making robots more autonomous, intelligent, and capable of interacting naturally with humans. There is a common interest in using humanoid robots to enhance productivity in manufacturing, logistics, and service industries, although the extent and nature of this application vary by region. Both Japan and Europe are particularly focused on using humanoid robots to address demographic challenges like providing care for aging populations, while China also sees them as a means to maintain economic growth amidst a shrinking workforce.

(Please find more in World Robotics R&D Programs 2025: <https://ifr.org/ifr-press-releases/news/robotics-research-government-programs-asia-europe-and-america-2025>)



Figure 7: Estun Codroid 02 showcased at automatica exhibition. Picture Source: Messe Munich

Ethical and regulatory considerations

A humanoid robot is a tool like any other type of robot, be it for the use of industrial or service tasks. Robots must assist humans, not the other way around. The European robotics industry therefore advocates a “human-in-command approach” for the design of good, safe workplaces. In the EU, humanoids using forms of AI also will fall under the regime of the EU AI Act.

Safety

As with any other piece of machinery, humanoid robots must be safe. The International Organization for Standardization (ISO) has set up a committee to address this issue. Its experts are working on safety requirements for industrial mobile robots with actively controlled stability, including those with legs, wheels or other means of locomotion. The very nature of an upright design presents challenges not faced by traditional static or robots on 4 wheels. Unlike robots with a low center of gravity or broad bases, humanoids must continuously maintain their balance. This significantly increases the risk of falling and requires complex recovery mechanisms to ensure safety, even in unpredictable

environments and when the power supply is switched off.

Economic view

From an economic point of view, the high cost of materials and components, as well as the complexity of the design and programming, makes widespread adoption difficult. This renders them unaffordable for cost-effective operations. Within the next 5 to 10 years, we can expect it to be more widely adopted in industry. Economies of scale need to be realized to substantially lower their unit costs and make them economically viable.

Outlook

Humanoids are not expected to replace the types of robots currently on the market. Instead, they will complement and expand upon existing technology, such as industrial robots and AMRs, while also introducing new ways of programming robots. As research and pilot programs continue to push the boundaries of what is possible, new control algorithms, sensor technology and energy management are expected to unlock sophisticated capabilities. Thanks to their human-like dexterity and adaptability, they are well-placed to automate

complex tasks that current robots struggle with using traditional programming methods. Mass adoption as universal household helpers will

not happen within the near- and medium-term future.

APPENDIX

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<https://www.iso.org/obp/ui/en/#iso:std:iso:10218:1:2011>

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<https://www.iso.org/obp/ui/en/#iso:std:iso:10218:2:2011>
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[Robotics Research: How Asia, Europe and America Invest - International Federation of Robotics](https://www.worldrobotics.org/research/how-asia-europe-and-america-invest-international-federation-robotics)

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Lists of Suppliers (status: 04/2025)

Legged

Company	Country	Region	Website
Sanctuary AI	Canada	Americas	https://sanctuary.ai/
Agility	USA	Americas	https://agilityrobotics.com/
Apptronik	USA	Americas	https://apptronik.com/
Boston Dynamics	USA	Americas	https://bostondynamics.com/
Figure	USA	Americas	https://www.figure.ai/
Laser Robotics	USA	Americas	https://laser-robotics.com/
Tesla	USA	Americas	https://www.tesla.com/AI
Westwood Robotics	USA	Americas	https://www.westwoodrobotics.io/
Agibot	China	Asia	https://www.agibot.com/
Beijing Humanoid Robot Innovation Center	China	Asia	
Booster Robotics (Beijing Accelerated Evolution Technology)	China	Asia	https://www.boosterobotics.com/
Deep Robotics	China	Asia	https://www.deeprobotics.cn/en
Dreame	China	Asia	https://global.dreametech.com/
Exrobots (Dalian TIACE Technology Development Co.)	China	Asia	https://www.exrobots.net
FDRobot (Sichuan Tianlian Robot Co)	China	Asia	https://www.fdrobot.com/
iFLYTEK	China	Asia	https://www.iflytek.com/
Kepler Exploration Robot Co	China	Asia	https://www.gotokepler.com/home
Leju (Shenzhen) Robotics	China	Asia	https://www.lejurobot.com/
LimX	China	Asia	https://www.limxdynamics.com/
Robotera (Beijing Xingdong Era Technology)	China	Asia	https://www.robotera.com/
Ti5 Robot	China	Asia	https://www.ti5robot.com/
UBTech Robot	China	Asia	https://www.ubtrobot.com/
Unitree Robotics (HangZhou YuShu TECHNOLOGY CO)	China	Asia	https://www.unitree.com/
Unix AI (Shanghai Euric Intelligent Technology)	China	Asia	
Vizum (Beijing Weijing Intelligent Technology)	China	Asia	www.vizumtech.com/
Xiaomi	China	Asia	https://www.mi.com/global/discover/article?id=2754
XPeng	China	Asia	https://www.xpeng.com/
Zhejiang Humanoid Robot Innovation Center	China	Asia	https://en.zhejianglab.com
Hanson Robotics	China	Asia	https://www.hansonrobotics.com/
Sirena Technologies	India	Asia	https://sirenatech.com/
Surena	Iran	Asia	https://surenahumanoid.com/
Fujisoft	Japan	Asia	https://www.fsi.co.jp/e/
Kawada	Japan	Asia	https://www.kawadarobot.co.jp/
Kawasaki	Japan	Asia	https://kawasakirobotics.com/

Toyota	Japan	Asia	https://global.toyota/en/newsroom/corporate/30609642.html
Rainbow Robotics	Korea	Asia	https://www.rainbow-robotics.com/
RobRos	Korea	Asia	https://robros.co.kr/
Fourier Intelligence	Singapore	Asia	https://fourierintelligence.com/
United Robotics Group	France	Europe	https://unitedrobotics.group/
Neura Robotics	Germany	Europe	https://neura-robotics.com/
Mentee Robotics	Israel	Europe	https://www.menteebot.com/
1X	Norway	Europe	https://www.1x.tech/
PAL Robotics	Spain	Europe	https://pal-robotics.com/
SKL ROBOTICS LTD (The Humanoid)	UK	Europe	https://thehumanoid.ai/
Engineered Arts	UK	Europe	https://engineeredarts.co.uk/

Wheeled

Company	Country	Region	Website
Agibot	China	Asia	https://www.agibot.com/
Alpha Robotics (Suzhou Pangolin Robot Co)	China	Asia	https://www.alpharobotics.com.cn/
Dataa Robotics	China	Asia	https://www.dataarobotics.com/
Elephant Robotics (Shenzhen Elephant Robot Technology)	China	Asia	https://www.elephantrobotics.com/en/
Galaxea (Xinghaitu (Suzhou) Artificial Intelligence Technology Co)	China	Asia	https://galaxea.ai/
Galbot	China	Asia	https://www.galbot.com/
PaXini Technology (Paxini Perception Technology)	China	Asia	https://paxini.com/index
Realman Robotics	China	Asia	https://www.realman-robotics.com/
Roboter (Beijing Xingdong Era Technology)	China	Asia	https://www.roboter.com/
Stardust Intelligence	China	Asia	https://astribot.com/
Ti5 Robot	China	Asia	https://www.ti5robot.com/
Unix AI (Shanghai Euric Intelligent Technology)	China	Asia	None found
Pudu Robotics	China	Asia	https://www.pudurobotics.com/
H-Bots Robotics	India	Asia	website currently suspended
Invento Robotics	India	Asia	https://mitrarobot.com/
Tokyo Robotics	Japan	Asia	https://robotics.tokyo/
Naver Labs	Korea	Asia	https://www.naverlabs.com/en/ambidex
Rainbow Robotics	Korea	Asia	https://www.rainbow-robotics.com/
Enchanted Tools	France	Europe	https://enchanted.tools/
United Robotics Group	France	Europe	https://unitedrobotics.group/
Unlimited Robotics	Israel	Europe	https://www.unlimited-robotics.com/
Oversonic	Italy	Europe	https://oversonicrobotics.com/
1X	Norway	Europe	https://www.1x.tech/
PAL Robotics	Spain	Europe	https://pal-robotics.com/

Upper-body only

Company	Country	Region	Website
Richtech Robotics	USA	Americas	https://www.richtechrobotics.com/
Boardwalk Robotics	USA	Americas	https://boardwalkrobotics.com/
Elephant Robotics (Shenzhen Elephant Robot Technology)	China	Asia	https://www.elephantrobotics.com/en/
iFLYTEK	China	Asia	https://www.iflytek.com/
Robotera (Beijing Xingdong Era Technology)	China	Asia	https://www.robotera.com/
Kawada	Japan	Asia	https://www.kawadarobot.co.jp/
Kawasaki	Japan	Asia	https://kawasakirobotics.com/
Yaskawa	Japan	Asia	https://www.yaskawa-global.com/
Macco Robotics	Spain	Europe	https://maccorobotics.es/
PAL Robotics	Spain	Europe	https://pal-robotics.com/
ABB	Switzerland	Europe	https://global.abb/
Engineered Arts	UK	Europe	https://engineeredarts.co.uk/