Issue Alert

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Humanoid Robots

Humanoid robots are undergoing rapid development, led by firms in the United States and China.[1] Recent advances in artificial intelligence (AI) have improved the degree of autonomy in humanoid robots, allowing them to handle more complex interactions with humans and their environment.[*] [2] These improvements are accelerating as robots use generative AI to learn new tasks, replacing what was previously accomplished through manual programming.[3] China has set a series of goals relating to the development of its humanoid robots sector, including having two to three humanoid robot firms that are global leaders by 2025.[4] Many other aspects of its stated goals, however, are vague and susceptible to multiple interpretations. While China's capacity to achieve these goals in the stated time frames may be doubtful, if their overall efforts are successful, humanoid robots could have transformative implications across commercial industries, including manufacturing, agriculture, and healthcare, and potentially for military and law enforcement as well.[5] The Chinese government has thrown its weight behind developing humanoid robots, as it has previously for other critical emerging technologies, with the aim of expanding its role in the global market.[6]

Humanoid robots are improving at navigating complex terrain and interacting with everyday objects.[7] Some humanoid robots have also been equipped with speech and reasoning capabilities to enhance communication options and help complete basic daily tasks.[8] Humanoid robot firms globally face technical obstacles, however, including the limited storage capacity of batteries that power the robots and the current technical limitations of components like actuators that allow the robot to move itself and manipulate other objects.[9] Far more progress is needed before humanoid robots will be able to reason through an unexpected situation and then act on it.[10]

[*] A number of leading robotics firms have released advanced prototypes, including U.S.-based Figure AI's Figure 01, Apptronik's Apollo, Boston Dynamics' Atlas, Agility Robotics' Digit, and Tesla's Optimus, as well as China-based Unitree's G1, UBTech's Walker S, and Fourier Intelligence's GR-1. Currently, their demonstrated skills include tasks such as sorting objects, cleaning, lifting and placing boxes, and walking, sometimes while interacting with humans. However, based on Commission analysis of company demonstration videos, humanoid robots appear to be slower than average humans at performing some of these fairly simple tasks. For example, it takes Optimus almost ten seconds to put an egg into an egg cooker and Figure 01 about four seconds to put a plastic cup in a drying rack. Rachel Cheung, "China's Robot Fever," *Wire China*, July 14, 2024. *https://www.thewirechina.com/2024/07/14/chinas-robot-fever-humanoid-robots-chinese*; Frédéric Schaeffer and Benoît Georges, "U.S. vs. China, Who Will Win the Race for Humanoid Robot Domination?" *Worldcrunch*, May 5, 2024. *https://worldcrunch.com/tech-science/humanoid-robots-china*; Figure, "Figure Status Update – OpenAI Speech-to-Speech Reasoning," Video, March 2024. *https://www.youtube.com/watch?v=Sq1QZB5baNw*; Tesla, "Optimus – Gen 2 | Tesla," Video, December 13, 2023. *https://www.youtube.com/watch?v=cpraXaw7dyc&t=23s*.

There are no general-purpose, autonomous humanoid robots constituting viable products today, whether for consumer, commercial, military,[*] or law enforcement purposes, and it is unclear when they will become available.[11] Select companies have announced that they are making humanoid robots commercially available now or in the near future.[†] [12] However, these robots still appear to have major limitations.[‡]

Defining Humanoid Robots

Humanoid robots are differentiated by their physical resemblance to humans and unique combination of three attributes: locomotion, dexterity, and intelligence.[13] Locomotion, or gross motor skills, allows for movement around human-oriented environments, such as navigating steps and uneven floors and avoiding obstacles.[14] Dexterity, or fine motor skills, allows humanoid robots to interact in useful ways with their environment to perform specific tasks, like picking up fragile objects without crushing them.[15] Intelligence in humanoid robots allows them to independently perceive and engage with the world around them and is increasingly powered by AI.[16] Humanoid robots increasingly employ machine learning techniques to learn from their interactions, which has put the industry on a path to potentially exponential growth in capabilities.[17] These robots use "embodied AI," the integration of AI software into physical hardware (such as robots), which allows them to sense, learn from, and interact with a physical environment.[§] [18]

How China Stacks Up

In characteristics like robot weight, height, and speed, Chinese humanoid robot firms appear to be competitive with non-Chinese firms.[19] However, Chinese robotics firms more broadly lag behind non-Chinese firms in hardware precision, durability, and reliability, according to a Chinese analyst.[**] [20] Furthermore, Chinese robotics firms have trailed firms in the United States, Japan, and Germany in developing key sensor technology important for movement.[21]

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[*] Mobile robots in other forms, such as semiautonomous robot dogs, are being developed for these purposes as well. Robot dogs are being tested for surveillance, reconnaissance, and combat, some with rifles and other weapons attached to their backs. Jared Keller, "Let Slip the Robot Dogs of War," *Wired*, June 16, 2024. *https://www.wired.com/story/let-slip-the-robot-dogs-of-war*.

[†] Chinese leadership has made reducing reliance on "chokepoint" technologies a central goal. Ben Murphy, "Chokepoints: China's Self-Identified Strategic Technology Import Dependencies," *Center for Security and Emerging Technology*, May 2022. *https://cset.georgetown.edu/publication/chokepoints*; Ryan Fedasiuk, Emily Weinstein, and Anna Puglisi, "China's Foreign Technology Wish List," *Center for Security and Emerging Technology*, May 2021. *https://cset.georgetown.edu/publication/chinas-foreign-technology-wish-list*.

[‡] China-based Unitree has announced a "mass production" humanoid robot called the G1 for $16,000. Other Chinese sources indicate that $16,000 is the price for a base model with delivery starting at the end of 2024. Its specifications include a carrying capacity of two to three kilograms (four to seven pounds), and only the more advanced G1 EDU model, which has no listed price, includes the option for dexterous hands. It is also unclear whether the G1 base model solely comprises the physical robot or if it also incorporates AI. Qin Sheng, "Humanoid Robots in View: Facing Homogeneity Challenges, How Long Until They Enter the Home?" (被围观的人形机器人：面临同质化挑战，多久能走进家庭), *Paper*, July 8, 2024. Translation. *https://web.archive.org/web/20240708010343/https://www.thepaper.cn/newsDetail_forward_27977296*; Unitree Robotics, "Unitree G1 Mass Production Version, Leap into the Future!" Video, August 19, 2024. *https://www.youtube.com/watch?v=FuNFr7V7KFQ*. *Unitree*, "Unitree G1." *https://shop.unitree.com/products/unitree-g1*.

[§] Several US companies, such as NVIDIA and Tesla, are leaders in embodied AI software and hardware. As discussed further in the note below, NVIDIA has introduced the Jetson Thor system-on-a-chip (Soc) hardware and a corresponding Gr00t AI foundational model for the development of embodied AI. Meanwhile, Tesla is using advanced VR motion capture software to gather millions of hours of data for the purpose of training its Optimus humanoid robot. Shubham Sharma, "Nvidia Shows Off Project GR00T, a Multimodal AI to Power Humanoids of the Future," *VentureBeat,* March 18, 2024; Jess Weatherbed, "Tesla is Hiring People to Do the Robot," *Verge,* August 19, 2024. *https://www.theverge.com/2024/8/19/24223626/tesla-optimus-humanoid-robot-motion-capture-training. https://venturebeat.com/ai/nvidia-shows-off-project-gr00t-a-multimodal-ai-to-power-humanoids-of-the-future*.

[**] Leading players in the humanoid robot industry tend to emphasize in-house design of core, specialized hardware components like actuators. *Tesla*, "Tesla Bot | Actuators Team," Video, January 21, 2023. *https://www.youtube.com/watch?v=1xChD-gv_pc*; *Apptronik*, "Meet Apollo, the 'iPhone' of Humanoid Robots." *https://apptronik.com/news-collection/meet-apollo-the-iphone-of-humanoid-robots*.

Leading U.S. and Chinese AI firms are currently in a race to build out the hardware/software technology stack required for humanoid robots. Based on limited on-the-ground reporting, NVIDIA appears to be the favored technology company for Chinese humanoid robot firms. According to Pandaily reporter Ni Tao, NVIDIA's AI stack of GPUs and software "ha[s] largely underpinned the development work at many Chinese [humanoid robot] startups."* [22] However, Chinese companies are also rapidly building out their own hardware/software stack for humanoid robots. In 2024, president of Huawei Cloud Zhang Pingan unveiled Huawei's partnership with domestic humanoid robot firm Leju.[23] Zhang explained that Leju's robot, Kuafu, was powered by Huawei's foundational AI model, Pangu, which itself is trained on Huawei's proprietary Ascend AI chips.[24] At an earlier conference, Leju announced that it was planning to build an "open platform" called "Humanoid Robot+," seeking "partners for joint innovation."[25] Like Huawei and Leju, other leading Chinese AI companies (Baidu, iFlytek) are also combining their AI models with the humanoid robot hardware of leading humanoid robot firms (UBTech Robotics, Zhiyuan Robotics) to achieve embodied AI.[26]

China's Playbook for Emerging Technology

China is deploying significant government support for the humanoid robot industry in the form of subsidies, tax breaks, and development zones, while pushing domestic adoption and public-private research collaboration.[27] China has used a similar multi-faceted approach to promote the development of critical emerging technologies and dominate the global supply of solar panels, electric vehicles, and commercial drones.[28] In 2023, the Ministry of Industry and Information Technology (MIIT) released a "Guiding Opinion on the Innovation and Development of Humanoid Robots."[29] The Guiding Opinion identifies humanoid robots as a key area for technological competition and calls for China to establish a world-class innovative ecosystem for humanoid robots by 2025.† [30] By 2027, MIIT calls for integrating humanoid robots into manufacturing supply chains, building an internationally competitive industrial environment, using them at scale, and expanding the use of humanoid robots throughout society.[31] To spur growth in the humanoid robots sector, government subsidies have been made available for Chinese robotics manufacturers, and local governments reportedly have played a role in brokering pilot programs between humanoid robot firms and state-owned factories.[32]

* NVIDIA has become a key player in the development of humanoid robots, despite not manufacturing a full robot itself. NVIDIA has developed tools including Isaac Sim, a virtual training ground for robots, GR00T, a general-purpose foundation model enabling humanoid robots to understand and respond to language, video, and human interaction, and Jetson Thor, a new computing platform designed specifically for humanoid robots and capable of performing complex tasks and interacting safely with people and machines. Both U.S. and Chinese firms are using NVIDIA's robotics development tools, including 1X, Boston Dynamics, Figure, Fourier, Galbot, and others. *NVIDIA*, "NVIDIA Accelerates Humanoid Robotics Development," July 29, 2024. *https://nvidianews.nvidia.com/news/nvidia-accelerates-worldwide-humanoid-robotics-development*; *NVIDIA*, "NVIDIA Announces Project GR00T Foundation Model for Humanoid Robots and Major Isaac Robotics Platform Update," March 18, 2024. *https://nvidianews.nvidia.com/news/foundation-model-isaac-robotics-platform*; *NVIDIA*, "NVIDIA Project GR00T." *https://developer.nvidia.com/project-gr00t*.

† While China's intention to be a global leader in the technology of humanoid robots is clear, some news outlets have indicated China intends to achieve "mass production" of humanoid robots by 2025. See, for example, Rachel Cheung, "China's Robot Fever," *Wire China*, July 14, 2024 (noting the MIIT Guiding Opinion states an "aim to mass produce humanoid robots by 2025"). This interpretation of China's time frame is flawed. The MIIT Guiding Opinion indicates that by 2025 China will have established a preliminary or early stage innovation system for humanoid robots ("到 2025 年，人形机器人创新体系初步建立"). In elaborating on this goal, the Guiding Opinion states China will by 2025 achieve international standards in humanoid robotics and implement what may be termed "batch production" or "production at scale" ("实现批量生产"), meaning they hope to have the ability to manufacture humanoid robots at some volume by 2025, not just create one-off laboratory prototypes, as part of developing the overall sector. The Guiding Opinion goes on to detail other basic humanoid robot technology goals for 2027, making it clear the language about production at scale in 2025 is not meant to imply China expects to have functioning humanoid robots rolling off assembly lines in mass by 2025. While "mass production" is a plausible interpretation of *piliang shengchan* 批量生产 in other contexts (and "mass production" is how Google Translate and DeepL, two popular machine translation tools, render 批量生产), it is not the most sensible translation of the Guiding Opinion in full context (Baidu's translation engine renders it as "volume production").

The exact scope of humanoid robot investment in China or, by comparison, the United States, is difficult to quantify because such investment is not typically broken out from broader robotics sector investment. One source reported that Chinese humanoid robot firms raised $769 million (RMB 5.4 billion) in 2023.[*] [33] In the first half of 2024, there were more than 22 financing events globally for Chinese humanoid robot-related firms, raising more than $997 million (RMB 7 billion).[34] Investors include Chinese technology giants, private equity firms, state-owned enterprises, and government funds.[35] In July 2024, Shanghai announced a $1.4 billion fund to support its local humanoid robots industry.[36] While large cross-industry tech firms like Huawei and Xiaomi are involved in humanoid robots, since January 2023, an additional 29 companies in China have been founded to focus specifically on humanoid robots (of which 22 have reportedly received funding from some source(s)).[†] [37] Among the most successful at raising capital are Zhiyuan Robotics, which has completed eight funding rounds since 2023, and UBTech Robotics, which has received $812 million (RMB 5.7 billion) in funding and was the first humanoid robot company to be listed on the Hong Kong Stock Exchange.[38]

Besides offering funding, provincial governments have sponsored the creation of shared collaborative robotics research facilities, often with a government-supported robotics research institute co-located with a host of Chinese robotics companies.[39] Since 2023, Beijing and Shanghai have both established new innovation centers focusing on humanoid robots, providing access to open-source humanoid robot prototypes and corresponding AI software with a goal to "further popularize the technology among enterprises to reduce development costs," according to the Shanghai center's general manager Xu Bin.[40] Beijing's high-tech Haidian District near Peking University and Tsinghua University is formulating a three-year initiative to promote the development of embodied AI and humanoid robots, bolstered by its ecosystem of universities, talent, research and development capabilities, and experience with product iteration.[41] Furthermore, the government is encouraging robotics researchers at universities, including at least one university supervised by China's defense agency, to collaborate with robotics companies.[42] According to Chinese state media, top universities in China have already played a role in patenting humanoid robot technologies.[43]

China is investing significant sums in the robotics sector more broadly, which China has identified as one of Xi Jinping's "new quality productive forces" sectors -- a slogan used to identify favored sectors for investment and economic growth.[44]

- From 2015 to 2019, Japan's RIETI think tank estimated that China's government subsidies of robotics increased over 200 percent, from $655 million (RMB 4.6 billion) to $2.2 billion (RMB 15.4 billion).[45]
- Provincial- and municipal-level governments have been a source of funding.
    - In January 2024, Beijing announced a $1.4 billion fund to develop its local robotics industry.[46] Outside of Beijing, Shenzhen allocated $71 million (RMB 500 million) yearly from 2014 to 2020 for funding robots and other intelligent technologies.[47]
    - Guangxi Province and Chengdu's Hi-Tech Zone have also pledged to support robotics. Guangxi Province has promised to issue up to $140,000 (RMB 1 million) in subsidies (per company) to local robotics companies. Meanwhile Chengdu has pledged $14.3 million (RMB 100 million) per major project, with an additional $1.4 million (RMB 10 million) promised to the first companies that sell an unspecified number of humanoid robots.[48]

[*] As discussed below, U.S. humanoid robot firms have also attracted significant investment. Joanna Glasner, "Robotics Startups on the Rise in 2024," *Crunchbase*, June 27, 2024. *https://news.crunchbase.com/robotics/humanoid-startup-venture-ai-2024-figure*; Harshita Mary Varghese and Krystal Hu, "Robotics Startup Figure Raises $675 Mln from Microsoft, Nvidia, OpenAI," *Reuters*, February 29, 2024. *https://www.reuters.com/technology/robotics-startup-figure-raises-675-mln-microsoft-nvidia-other-big-techs-2024-02-29.*

[†] The underlying source does not identify from what entity or entities the funding originated.

The U.S. government has also provided public sector support for robotics,[*] and Crunchbase reports that private funding to U.S. robotics startups has been robust, at $6.8 billion in 2023 and $4.2 billion through June 27, 2024, with at least $773 million of that figure going to startups working on humanoid robots.[49] One report by Goldman Sachs estimates the market for humanoid robots globally is expected to hit $38 billion by 2035, which suggests interest in humanoid robot firms will likely continue for the foreseeable future.[50]

While Japan's Fanuc, Germany's Kuka,[†] and Switzerland's ABB lead the industrial robotics market, China has a significant presence.[51] Many of the leading robotics firms have major production facilities in China, and since 2017 there have been over 3,400 robotics startups in China, many in Songshan Lake, an industrial development zone south of Dongguan, China, that has hundreds of robotics companies.[52] Moreover, China has robust domestic market demand for robotics; it ranks as the world's largest industrial robot market, accounting for 52 percent of robot installations worldwide.[53] China also has the world's fifth-highest robot density, at 392 robots per 10,000 employees, while North America ranks 10th globally in robot density, at 188 robots per 10,000 employees.[‡] [54] This density translates into China having more than 1.5 million robots operating throughout its factories.[55]

Future of Humanoid Robots in China

According to Chinese industry representatives, humanoid robots in China are undergoing limited deployment in education, entertainment, healthcare, elder care, and manufacturing; these robots are primarily used for research, and humanoid robot firms are not generating commercial sales yet.[56] However, the rapidly declining cost of producing humanoid robots will allow for more widespread adoption.[57] According to a global analysis by Goldman Sachs, from 2023 to 2024 the manufacturing cost of humanoid robots has declined 40 percent.[58] China's goal for the widespread deployment of humanoid robots in China could have transformative effects on China's economy and society, posing a potential solution to an aging population and increasing labor costs. For example, humanoid robots could replace humans on manufacturing assembly lines, or in dangerous work environments involving hazardous waste or mining.[59]

While humanoid robots are most often pitched by Chinese firms for their commercial uses, China's policy of military-civil fusion leverages commercial technologies for the advancement of China's military, blurring the boundaries of what constitutes a commercial enterprise or military product.[60] Chinese military analysts have put forth new theories of human-robot cooperation if the technology advances, such as replacing front-line soldiers with humanoid robots while humans maintain control of command and decision making.[§] [61]

Considerations for Congress

- The development of humanoid robots has undergone significant progress in the past two years powered by advances in AI. The newest generation of humanoid robots exhibit more advanced reasoning capabilities in interactions with humans and their environments. Although humanoid robots are not currently

[*] Public Spend Forum estimates that the U.S. government spent over $6 billion on robotics, automation, and advanced manufacturing-related research and development across all agencies during FY2018–FY2022. Public Spend Forum, "Robotics, Automation, and Advanced Manufacturing." *https://www.publicspendforum.net/robotics-automation*.

[†] Kuka is owned by Chinese consumer products firm Midea. Qiaoyi Li and Kevin Krolicki, "China's Robot Makers Chase Tesla to Deliver Humanoid Workers," *Reuters,* August 23, 2024. *https://www.reuters.com/technology/chinas-robot-makers-chase-tesla-deliver-humanoid-workers-2024-08-23*.

[‡] Robot density is the number of operational industrial robots relative to the number of employees.

[§] One analyst has described how humanoid robots could play a role in a Taiwan invasion scenario if the technology becomes sufficiently advanced. Fu Qianshao, "The Rise of China's Humanoid Robot Industry Will Replace the People's Liberation Army in Performing Tasks, Making the Great Task of Reunification Easier" (中国人形机器人产业崛起，代替解放军执行任务，让统一大业更轻松), *Gaze into the Sky [NetEase Blog]*, April 15, 2024. Translation. *https://web.archive.org/web/20240430181509/https:/www.163.com/dy/article/IVQR04OO0535T18G.html*.

commercially viable at scale, falling production costs and rapid technological advancements mean that the industry could be approaching significantly wider deployment.

- Critical technology is concentrated in a handful of companies that specialize in creating in-house sensors and actuators, advanced hardware such as GPUs, and relevant AI models. China is trying to innovate in its domestic robotics market to eliminate its reliance on technology where U.S. and other non-Chinese firms dominate.[62] As they have in other industries, Chinese firms are rapidly catching up.[63]
- China is relying on a familiar playbook in which significant coordinated government support is funneled into humanoid robot development to rapidly ramp up domestic technological development and manufacturing, with the goal of becoming a dominant player in global markets. China's broader domestic robotics market indicates China is a fast adapter of robotics technologies.
- Once the technology is sufficiently advanced and affordable, humanoid robots could have serious implications for a wide variety of commercial industries by resolving labor shortages and reducing costs. In addition, when sufficiently advanced, humanoid robots could transform military conflict by replacing or supplementing human personnel on the battlefield.

Endnotes

[1] Frédéric Schaeffer and Benoît Georges, "U.S. vs. China, Who Will Win the Race for Humanoid Robot Domination?" *Worldcrunch*, May 5, 2024. *https://worldcrunch.com/tech-science/humanoid-robots-china*.

[2] Cristina Criddle, Madhumita Murgia, and George Hammond, "Artificial Intelligence Breakthroughs Create New 'Brain' for Advanced Robots," *Financial Times*, July 26, 2024. *https://www.ft.com/content/bea9df71-371c-4045-9cb4-64c22789bf7b*.

[3] Cristina Criddle, Madhumita Murgia, and George Hammond, "Artificial Intelligence Breakthroughs Create New 'Brain' for Advanced Robots," *Financial Times*, July 26, 2024. *https://www.ft.com/content/bea9df71-371c-4045-9cb4-64c22789bf7b*.

[4] Ministry of Industry and Information Technology, *Guiding Opinion on the Innovation and Development of Humanoid Robots* (人形机器人创新发展指导意见), November 2, 2023, 2. Translation. *https://web.archive.org/web/20231102145104/https://www.miit.gov.cn/zwgk/zcwj/wjfb/tz/art/2023/art_48fe01d562644aedb7ea3f4256df8190.html*.

[5] Wang Huawei, "Discussing Criminal Liability in the Governance of Humanoid Robots" (论人形机器人治理中的刑法归责), May 20, 2024. Translation. https://web.archive.org/web/20241001193945/http://www.chv.org.cn/sjzk/1358.html; "The Rise of China's Humanoid Robot Industry Will Replace the People's Liberation Army in Performing Tasks, Making the Great Task of Reunification Easier" (中国人形机器人产业崛起，代替解放军执行任务，让统一大业更轻松), Gaze Into the Sky [NetEase Blog], April 15, 2024. Translation. *https://web.archive.org/web/20240430181509/https:/www.163.com/dy/article/IVQR04OO0535T18G.html*; Ministry of Industry and Information Technology, *Guiding Opinion on the Innovation and Development of Humanoid Robots* (人形机器人创新发展指导意见), November 2, 2023, 2, 6. Translation. *https://web.archive.org/web/20231102145104/https://www.miit.gov.cn/zwgk/zcwj/wjfb/tz/art/2023/art_48fe01d562644aedb7ea3f4256df8190.html*.

[6] Ji Siqi, "China Targets 'Future Industries' in 2024, Humanoid Robots and Biomedicines to Drive High-Quality Economic Growth," *South China Morning Post*, December 23, 2023. *https://www.scmp.com/economy/china-economy/article/3246040/china-targets-industries-future-2024-humanoid-robots-and-biomedicines-drive-high-quality-economic*; Ministry of Industry and Information Technology, *Guiding Opinion on the Innovation and Development of Humanoid Robots* (人形机器人创新发展指导意见), November 2, 2023, 9–10. Translation. *https://web.archive.org/web/20231102145104/https://www.miit.gov.cn/zwgk/zcwj/wjfb/tz/art/2023/art_48fe01d562644aedb7ea3f4256df8190.html*.

[7] Tadeusz Mikolajczyk et al., "Recent Advances in Bipedal Walking Robots: Review of Gait, Drive, Sensors and Control Systems," *Sensors* 22:12 (June 2022). *https://www.mdpi.com/1424-8220/22/12/4440*; Joshua Stewart, "This Robot's Gentle Grip Can Harvest Berries and Other Delicate Fruit," *Wallace H. Coulter Department of Biomedical Engineering*, May 25, 2022. *https://bme.gatech.edu/bme/news/robots-gentle-grip-can-harvest-berries-and-other-delicate-fruit*; Marc Raibert and Lex Fridman, Lex Fridman Podcast, "Hydraulic vs Electric Actuation in Robotics," Video. *https://www.youtube.com/watch?v=6r6KPuJ689o*.

[8] Paul Ridden, "Video: GPT-Enhanced Humanoid Speaks and Reasons as it Works," *New Atlas*, March 13, 2024. *https://newatlas.com/robotics/figure-01-openai-humanoid-robot-real-time-conversations/*.

[9] Evan Ackerman, "Humanoid Robots Are Getting to Work," *IEEE Spectrum*, December 30, 2023. *https://spectrum.ieee.org/humanoid-robots*; Randal C. Nelson, "Robot Actuators," *University of Rochester*, https://www.cs.rochester.edu/u/nelson/courses/csc_robocon/robot_manual/actuators.html.

[10] Charlie Kemp, "It Cooks, It Cleans! When Will Robots Be Doing Our Chores?" *Wall Street Journal*, Podcast, September 13, 2024. *https://www.wsj.com/podcasts/wsj-the-future-of-everything/it-cooks-it-cleans-when-will-robots-be-doing-our-chores/dd4b245a-7e26-42bf-bfca-ebed68903433*; Nick Huber, "'Humanoid' Robot Wave Signals Change on the Production Line," *Financial Times*, March 26, 2024. https://www.ft.com/content/613cb2c6-7067-413f-a3cf-747519b407c2 .

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[16] Brian Heater, "Large Language Models Can Help Home Robots Recover from Errors without Human Help," *TechCrunch*, March 25, 2024. https://techcrunch.com/2024/03/25/large-language-models-can-help-home-robots-recover-from-errors-without-human-help.

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