
Testimony Before the U.S.-China Economic and Security Review Commission's hearing
"Made in China 2025—Who Is Winning?"

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## Executive Summary

- **China’s Robotics and AI Expansion**
  Under the "Made in China 2025" strategy, China has become a dominant force in AI-driven robotics and autonomous technologies, leveraging state-led investment and supply chain consolidation. It leads in industrial robotics, humanoid robots, UAVs, and UUVs, with companies advancing cost-effective automation. However, China remains reliant on foreign suppliers for critical robotics components, including high-performance AI chips, torque sensors, harmonic drives, and lightweight engineering materials such as carbon fiber and PEEK. Despite this, China is aggressively localizing production and expanding its presence in global robotics markets.
- **Military AI and Autonomous Warfare**
  The PLA is integrating AI into combat operations, developing autonomous decision-making systems, AI-powered drone swarms, robotic infantry, and UUVs for naval warfare. These technologies enable faster battlefield coordination and reduce reliance on human oversight, potentially giving China a tactical advantage in high-speed conflicts. However, the PLA’s centralized command structure may slow the transition to fully autonomous warfare.
- **Challenges in China’s Robotics Sector**
  Despite its rapid progress, China’s robotics industry faces structural weaknesses, including dependency on foreign high-end actuators, AI processors, and industrial automation components. The high cost of lightweight materials limits efficiency improvements in humanoid and industrial robots. Currently, most of China’s industrial robots are used for basic manufacturing tasks, with limited AI-driven intelligence, causing more time to automate its key industries.
- **U.S. Strategic Response**
  The U.S. must strengthen domestic AI and robotics leadership by investing in next-generation technologies and reforming military procurement to prioritize AI-integrated warfare. Targeted export controls should limit China’s access to critical AI chips, robotic actuators, and navigation sensors. Strategic cooperation with allies such as Japan, Germany, and South Korea is essential to securing key supply chains and preventing technology transfers that could enhance China’s autonomous military capabilities.
- **AI-Integrated Defense and OSINT Expansion**
  To counter China’s advancements, the U.S. should expand research and deployment of AI-driven combat systems, including swarm drone countermeasures, autonomous UAVs, and AI-enhanced decision-making tools. Establishing a dedicated OSINT agency will be critical to tracking China’s technological developments, industrial policies, and supply chain vulnerabilities, ensuring long-term strategic advantages.

## I. Overview[1]

Co-Chairs: Vice Chair Randall Schriver and Commissioner Michael Kuiken - Thank you for the opportunity to testify today on Made in China 2025. My testimony will focus on one of the most critical objectives within this industrial strategy—advancing robotics and autonomous technologies. I will provide an overview of China's strategic approach, key industry players, and the broader economic and geopolitical ramifications of its rapid advancements in these sectors.

"Made in China 2025" (MIC 2025) was introduced in 2015 as China's strategic industrial policy aimed at transforming the nation from a manufacturing powerhouse known for low-cost labor into a global leader in high-tech industries. MIC 2025 identified ten key sectors for targeted development, including robotics, high-end CNC (computer numerical control) machine tools, AI, new-energy vehicles, aerospace, and biopharmaceuticals. The plan emphasized technological self-sufficiency, innovation-driven development, and industrial upgrading, reducing reliance on foreign suppliers, particularly in critical technologies like semiconductors, automation, and artificial intelligence.

Although China officially downplayed MIC 2025 in public discourse after facing strong backlash from the United States and other Western countries—who viewed it as an aggressive industrial strategy threatening global competition—the plan's objectives never disappeared. Instead, they were integrated into a broader range of policies and state-led initiatives that continued to receive extensive financial and political support. Over the past decade, China has implemented massive subsidies, state-backed investment funds, and regional development policies to accelerate the growth of strategic industries, particularly robotics and automation, as part of a broader push to enhance national technological sovereignty.

Robotics has been a major focus within this framework, with the MIC 2025 blueprint outlining specific goals to advance industrial robots, special-purpose robots, and service robots.[2] Industrial robots are designed for the manufacturing sector and include multi-joint mechanical arms and multi-degree-of-freedom robots that automate repetitive, monotonous tasks such as welding, material handling, packaging, painting, cutting, and operations in clean rooms. Service robots provide essential services to humans in unstructured environments and encompass domestic robots, medical service robots, and public service robots that operate in agriculture, finance, logistics, and education. Special-purpose robots are developed to perform in hazardous environments and under unique conditions, including military applications, extreme operations, and emergency rescue missions. This categorization has allowed for targeted policy measures and industry-specific support, leading to remarkable growth across all three segments.[3] [4]The plan

[1] The opinions and conclusions expressed in this testimony are the author's alone and should not be interpreted as representing those of The Jamestown Foundation or any of the sponsors of its research.

[2] "Made in China 2025: Promoting Robotics Development" [《中国制造 2025》解读之：推动机器人发展], PRC State Council, 2016, at https://archive.ph/TWqyH#selection-325.9-325.30

[3] Ibid.

[4] "State Council Issues 'Made in China 2025' Outlining Nine Strategic Tasks and Priorities" [国务院印发《中国制造 2025》明确 9 项战略任务和重点], HuanQiu, 2015, at https://finance.huanqiu.com/article/9CaKrnJLa0y

called for breakthroughs in key components such as high-precision servo motors, reducers, sensors, and intelligent control systems, recognizing that reliance on foreign technology in these critical areas hindered China's ability to dominate the global market.

Building on MIC 2025, China reinforced its commitment to robotics with three major national plans in 2021. The 14th Five-Year Plan (2021-2025) (十四五规划) prioritized robotics and automation as key drivers of industrial transformation.[5] In April 2021, the "14th Five-Year Plan for Intelligent Manufacturing Development" (《"十四五"智能制造发展规划》) outlined R&D priorities for intelligent welding robots, smart mobile robots, and semiconductor (cleanroom) robots.[6] By December, the "14th Five-Year Plan for Robotics Industry Development" (《"十四五"机器人产业发展规划》) set a clear goal for China to become a global leader in robotics innovation, high-end manufacturing, and integrated applications by 2025, targeting breakthroughs in core technologies and high-end products while ensuring key components match international standards. The industry is projected to maintain an annual revenue growth rate of over 20% during this period.[7]

Further strengthening its robotics strategy, the 2023 "Robotics+ Application Action Plan" (《机器人+"应用行动实施方案》) aimed to boost robotics density in manufacturing and expand their use in healthcare, logistics, education, and household services.[8] On the other hand, the 2023 "Humanoid Robotics Innovation Development Guidelines" (《人形机器人创新发展指导意见》) emphasized advancements in high-torque density servo motors, intelligent motion planning, bionic perception, and cognitive AI—essential for developing humanoid robots.[9] In 2024, the "Guiding Opinions on Promoting the Innovative Development of Future Industries" (《关于推动未来产业创新发展的实施意见》) further reinforced this focus, detailing key breakthroughs in servo motors, dynamic motion control, bionic perception, cognitive systems, dexterous robotic hands, and electronic skin technology[10].

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[5] "Outline of the 14th Five-Year Plan for National Economic and Social Development and Long-Range Objectives Through the Year 2035" [《中华人民共和国国民经济和社会发展第十四个五年规划和 2035 年远景目标纲要》], PRC State Council, 2021, at https://www.gov.cn/xinwen/2021-03/13/content_5592681.htm

[6] "14th Five-Year Plan for Intelligent Manufacturing Development" [《"十四五"智能制造发展规划》], PRC State Council, 2021, at https://www.gov.cn/zhengce/zhengceku/2021-12/28/content_5664996.htm

[7] "14th Five-Year Plan for the Development of the Robotics Industry" [《"十四五"机器人产业发展规划》], Ministry of Industry and Information Technology of the People's Republic of China, 2021, at https://www.gov.cn/zhengce/zhengceku/2021-12/28/content_5664988.htm

[8] "Robot+ Application Action Plan" [《"机器人+"应用行动实施方案》], Ministry of Industry and Information Technology of the People's Republic of China, 2023, at https://www.gov.cn/zhengce/zhengceku/2023-01/19/content_5738112.htm

[9] "Guiding Opinions on Innovative Development of Humanoid Robots" [《人形机器人创新发展指导意见》], Ministry of Industry and Information Technology of the People's Republic of China, 2023, at https://www.gov.cn/zhengce/zhengceku/202311/content_6913398.htm

[10] "Implementation Opinions on Promoting Innovative Development of Future Industries" [《关于推动未来产业创新发展的实施意见》], Ministry of Industry and Information Technology of the People's Republic of China, 2024, at https://www.gov.cn/zhengce/zhengceku/202401/content_6929021.htm

China's approach to achieving these goals has been multifaceted. The government provided direct financial support through subsidies and tax incentives, making it easier for companies to invest in robotics research and development. Provincial and municipal governments also introduced targeted programs to build local robotics clusters, offering grants and preferential policies to incentivize both state-owned enterprises and private firms to accelerate innovation. As a result, China has not only emerged as the world's largest market for industrial robots but also significantly enhanced its domestic manufacturing capabilities. In 2022, China accounted for 52 percent of all industrial robot installations worldwide, a dramatic increase from just 14 percent a decade earlier.[11]

China's regional governments have also actively supported the robotics industry through localized initiatives. For example, Jiangsu province aims to establish a robotics industry chain worth over 2,000 billion RMB by 2025, while Shanghai is creating a National Humanoid Robotics Innovation Center to drive advancements in smart manufacturing and automation. Similarly, provinces like Zhejiang, Shandong, Chongqing, and Anhui have rolled out targeted robotics action plans, each designed to promote the commercialization and mass production of advanced robots across different sectors.[12]

The results of these sustained efforts are evident in the rapid rise of leading Chinese robotics companies such as UBTech, Fourier Intelligence, Unitree Robotics, and major tech giants like Xiaomi and XPeng, which have expanded into humanoid robotics development. These companies are increasingly competitive in global markets, not just as adopters of automation but as innovators producing cutting-edge robotic systems with intelligent AI integration.

## II. Supply Chain and Key Components for Humanoid Robots

Key Technological Modules of Humanoid Robots[13]

| Module | Key Components |
|---|---|
| Environmental Perception Module | Various Sensors, LiDAR, Ultrasonic Sensors, 3D Vision Cameras, Infrared Sensors |
| AI Chipset Module | AI Processors, Neural Network Accelerators, Memory & Storage, Machine Learning Optimization |
| Motion Control Module | Controllers, Actuation Systems, High-Precision Reducers, Robotic Joints, Balance Control Systems |
| Operating System Module | Real-Time OS, Human-Robot Interaction, AI Behavior Adaptation, Cloud Integration |

[11] World Robotics 2023 – Extended Version" [World Robotics 2023 – Extended Version], International Federation of Robotics (IFR), 2023, at https://ifr.org/img/worldrobotics/2023_WR_extended_version.pdf
[12] See Appendix
[13] Author's analysis

**Actuators and Robotic Joints**

Actuators serve as the fundamental drivers of robotic movement, effectively acting as the "muscles" of humanoid robots and drones. These components enable robots to execute precise, controlled movements essential for tasks such as walking, grasping objects, and navigating complex environments.[14]
Precision reducers serve as the intermediate mechanism between power sources and actuators, allowing for controlled speed matching and torque transmission. In industrial robotics, nearly every joint is equipped with a reducer to achieve precise movement control. The two primary types of reducers used in industrial robots are RV reducers (RV 减速器) and harmonic reducers (谐波减速器), each hold around 40% of the market share in the global market.[15] RV reducers are typically applied to the base and large arms of industrial robots due to their strength and load-bearing capabilities, whereas harmonic reducers are preferred for smaller arms, wrists, and hands due to their lightweight and high precision.[16]

The harmonic drive gear (谐波减速器), an advanced gear system allows for high-precision lightweight motion with minimal backlash, , has been an ideal solution for humanoid robots which requires smooth articulation. A prime example of harmonic reducer application is Tesla's Optimus humanoid robot, which employs 14 harmonic reducers across various joints, ensuring precise and fluid motion.[17] Harmonic drives operate using a wave generator, a flexible gear (flexspline), and a rigid gear (rigid spline). By leveraging controlled elastic deformation, these gears ensure smooth, precise movement while maintaining a compact form factor.[18]

Japan’s Harmonic Drive Systems has held an overwhelming market share, holding a staggering 80% of the international market. However, Chinese firms such as Suzhou Green Harmonic (绿的谐波) have emerged as strong competitors, now capturing approximately 26% of the domestic market, largely due to policy-driven investments aimed at achieving self-sufficiency.[19] Other key Chinese manufacturers such as ZhongDa Leader (中大力德) and Hubei Kofon Intelligent Transmission (科峰智能) are actively expanding their presence in the planetary and RV reducer

[14] "Three Methods for Calculating the Transmission Ratio of Planetary Gear Mechanisms and Their Comparison"[《三种计算行星齿轮机构传动比的方法及其比较》], Xiao Min (肖敏), Zeng Xiaolan (曾小兰), Journal of Mechanical Engineers [《机械工程师》], No. 11, 2006.
[15] Other types such as precision planetary reducers and cycloidal reducers accounting for the remaining 20%
[16] Research Status of Precision Reducers for Industrial Robots" [《工业机器人用精密减速器研究现状》], Lin Jianghai (林江海), Modern Manufacturing Technology and Equipment [《现代制造技术与装备》], 2024, at https://archive.ph/861Qa#selection-359.21-359.39.
[17] "Another Look at the Tesla Robot: The Planetary Roller Screw" [Another Look at the Tesla Robot: The Planetary Roller Screw], KGG Robots, 2023, at https://www.kggfa.com/news/another-look-at-the-tesla-robot-the-planetary-roller-screw/
[18] Ibid.
[19] Jamestown’s analysis based on MIR Databank

markets.[20] [21]Although China still lags behind Japan in terms of overall precision and durability, aggressive government support and investment in R&D have incrementally narrowed the technological gap.

**Ball Screws and Their Role in Robotics**

Ball screws (丝杠) are a core component of robotic linear joints, playing a crucial role in converting rotary motion into linear displacement. Ball screws are classified into three types based on friction characteristics: sliding screws (滑动丝杠), rolling screws (滚动丝杠), and hydrostatic screws (静压丝杠). Among these, rolling ball screws are the most widely used in industrial automation, with two major subtypes: ball screws (滚珠丝杠) and planetary roller screws (行星滚柱丝杠).[22]

In the humanoid robotics sector, ball screws are primarily used in linear joints, including robotic arms and legs. Planetary roller screws and sliding screws are preferred for high-load applications such as robot arms and thighs due to their high precision, durability, and impact resistance. Compared to traditional ball screws, planetary roller screws offer superior precision, speed, and lifespan, making them a preferred choice for high-performance humanoid robots.[23]

China's high-end ball screw market remains largely dominated by Japanese and European manufacturers, with key players including THK (Japan), NSK (Japan), Rollvis (Switzerland), GSA (Switzerland), Ewellix (Sweden), and Rexroth (Germany). According to industry reports, Japanese and European manufacturers controlled approximately 90% of China's planetary roller screw market in 2022, underscoring the significant technological gap between domestic and international firms.[24]

The primary barriers to China’s advancement in precision ball screws lie in manufacturing expertise, advanced machinery, and material processing. High-precision ball screw production involves dozens of machining steps, including turning, heat treatment, grinding, and surface finishing, requiring exceptional technical precision at tolerances as fine as P1-level accuracy.

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[20] "Company Overview: Ningbo ZhongDa Leader Intelligent Transmission Co., Ltd." [Company Overview: 宁波中大力德智能传动股份有限公司], Ningbo ZhongDa Leader Intelligent Transmission Co., Ltd., at https://f10.eastmoney.com/CompanySurvey/Index?code=SZ002896&type=soft.

[21] "Company Overview: Hubei Kofon Intelligent Transmission Co., Ltd." [Company Overview: 湖北科峰智能传动股份有限公司], Hubei Kofon Intelligent Transmission Co., Ltd., at https://www.kofon.com.cn.

[22] Modeling, Simulation, and Experimental Research on Electro-Mechanical Braking" [《电子机械制动的建模、仿真和实验研究》], "Metal Cutting Machine Tools (3rd Edition)" [《金属切削机床（第 3 版）》], 2022.

[23] "Discussion on the Plastic Forming of Planetary Roller Screw Mechanism" [《行星滚柱丝杠副滚柱塑性成形的探讨》], Zhang Dawei (张大伟) and Zhao Shengdun (赵升吨), 2015.

[24] Robot Ball Screws: Focus on Product Iteration and Domestic Substitution, with Processing Equipment and Cutting Tools Benefiting Simultaneously" [《机器人丝杠，关注产品迭代和国产化，加工设备和刀具同步受益》], Shenwan Hongyuan Research [申万宏源研究], 2022

Additionally, high-precision manufacturing depends on skilled labor and specialized equipment, which has historically been dominated by overseas manufacturers.[25]

**Sensors and Perception Systems**

Robotic intelligence depends on sensors to interpret both external and internal data, enabling autonomous decision-making and adaptability. Sensors are categorized into internal and external types. Internal sensors measure the robot's motion state, including kinematic and force data, allowing precise control over movement. External sensors detect environmental conditions, such as vision and force interactions, enabling robots to interact with their surroundings. Different robotic applications require varying sensor types. Industrial robots rely on positioning, force, touch, and vision sensors for assembly and logistics operations. Specialized robots may integrate advanced cameras, microphones, temperature sensors, and light sensors to adapt to diverse environments and user needs.[26] As robotic applications evolve, the demand for advanced sensor integration is increasing, enhancing adaptability and operational intelligence.

Torque sensors are crucial in robotics, converting mechanical force into electrical signals for precise force measurement. Based on different working principles, torque sensors are categorized into strain gauge, inductive, capacitive, photoelectric, and electromagnetic sensors.[27] Among these, strain gauge sensors dominate the market due to their maturity and reliability, functioning by detecting strain-induced resistance changes to produce measurable electrical signals. According to IMARC Group, the global torque sensor market reached $8.2 billion in 2022 and is projected to grow to $13.7 billion by 2028, reflecting a 9.2% CAGR. Leading global manufacturers include HBM (Germany), Vishay (USA), Mettler Toledo (USA), and Flintec (Sweden).[28]

Six-axis force sensors provide multi-dimensional force feedback, allowing robots to perform intricate tasks requiring precise force perception. They are essential in robotic automation, automotive testing, medical technology, aerospace, and scientific research. Due to their complexity, these sensors have high technical barriers, making large-scale production challenging. ATI (USA) dominates the global six-axis force sensor market, maintaining a leadership position in robotic force measurement solutions. In China, companies such as Kunwei Technology (坤维科技), Yuli Instruments (宇立仪器 ), Xinjingcheng (鑫精诚) and others are advancing in collaborative robotics applications.[29] [30]However, domestic manufacturers still lag in

[25] Ibid.
[26] Shenzhen Xinjingcheng Technology Co., Ltd. Official Website" [深圳市鑫精诚科技有限公司官方网站], at https://www.xjc18.com.
[27] Torque Sensor Market Report 2024-2032" [Torque Sensor Market Report], IMARC Group, 2024, at https://www.imarcgroup.com/torque-sensor-market.
[28] Ibid.
[29] "Kunwei Technology Official Website" [《坤维科技官方网站》], Kunwei Technology (坤维科技), at https://www.kunweitech.com.
[30] "Yuli Instruments Official Website" [《宇立仪器官方网站》], Yuli Instruments (宇立仪器), at https://www.srisensor.com.cn.

sensitivity, overload resistance, and signal interference reduction. Continued R&D investments are helping to close this gap, improving sensor performance and reliability.

Six-axis force sensors are among the most expensive components in humanoid robots. GG Robotics estimates that force sensors used in robotic joints and end-effectors contribute up to 15% of total component costs.[31] Their complexity and precision make large-scale production difficult. Despite high costs, the six-axis force sensor market remains relatively small and has yet to reach full commercialization. However, growing industry participation and cost reduction efforts are accelerating adoption. Chinese manufacturers are focusing on product validation and industrial applications, paving the way for mass production and lower costs in the near future.

**Motors**

Coreless Motors (空心杯电机)
Coreless motors, a type of servo control motor, are widely used in robotics due to their lightweight and high efficiency. These motors are valued for their fast response, low inertia, and smooth motion control, making them particularly useful for humanoid robots where precision movement is essential.

Currently, the global coreless motor market is dominated by Maxon (Switzerland), Faulhaber (Germany), and Portescap (Switzerland), which lead in performance and reliability. Chinese manufacturers, such as Mingzhi Electric (鸣志电器), have made advancements, gradually closing the technological gap. Domestic firms are leveraging cost advantages and increasing R&D investment to compete with leading global players, with further market expansion expected as downstream applications grow.[32]

Frameless Torque Motors (无框力矩电机)
Frameless torque motors, a type of servo motor, consist solely of a rotor and a stator, without an outer housing. This unique structure allows for flexible integration into robotic systems, making them ideal for collaborative robots (协作机器人) and industrial automation applications. Their compact size, lightweight construction, and adaptability to various configurations align with the increasing trend of integrated robotic drive systems.

Major global manufacturers of frameless torque motors include Kollmorgen (USA), TQ RoboDrive (Germany), and Moog (USA). In China, Buke Co. q are emerging leaders in this field. While domestic products are becoming increasingly competitive, international brands still dominate applications requiring extreme precision, such as surgical robots. However, in collaborative robotics, the adoption of Chinese-made frameless torque motors has been steadily increasing due to their cost advantages.[33]

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[31] "Six-Axis Force Sensors: A Key Component Track for Humanoid Robots, Leading Companies Strengthen Their Dominance" [《六维力传感器：人形机器人零部件关键赛道，龙头强者恒强》], Baijiahao, 2023, at https://baijiahao.baidu.com/s?id=1787142519965387411

[32] "Analysis of Coreless Motor Companies and Overview of Technical Barriers" [《空心杯电机企业梳理、技术壁垒一览》], Motor Alliance [电机联盟], January 27, 2025.

[33] Ibid.

**Rare Earth Permanent Magnets**

High-performance neodymium-iron-boron (NdFeB) (高性能钕铁硼永磁材料) magnets are crucial in servo motors, enabling compact, efficient designs with strong magnetic properties. These magnets are essential in humanoid robotics, where high torque density and energy efficiency are key.[34] For example, based on estimation, Tesla's Optimus robot uses 28 frameless torque motors and 34 coreless motors, requiring about 4.5 kg of high-performance NdFeB per unit.[35] If the industry scales to 10 million units, demand for these magnets would rise by 45,000 tons, fueling significant sector growth.

Recognizing their strategic importance, China has enacted policies to accelerate NdFeB development. The 2016 "New Materials Industry Development Guide" (《新材料产业发展指南》), issued by MIIT, NDRC, MOST, and the Ministry of Finance, classified high-performance NdFeB as a "key strategic material," promoting energy-efficient rare earth magnet motors.[36] In 2021, MIIT reinforced this priority by including them in the "Key New Materials First Batch Application Demonstration Guide" (《重点新材料首批次应用示范指导目录（2021 年版）》), supporting commercialization and scaling.[37]

China leads global sintered NdFeB magnet production, exceeding 230,000 tons in 2022, yet only 64,000 tons (less than 30%) met high-performance standards.[38] Leading Chinese producers are expanding capacity. JL MAG (金力永磁), a global leader, had 23,000 tons of capacity as of Q1 2024 and plans to reach 40,000 tons by 2025, including advanced magnet assembly lines. Ningbo Yunsheng (宁波韵升), another top producer, had 21,000 tons of capacity by mid-2024 and is developing a 15,000-ton intelligent manufacturing project in Baotou.[39] With strong policy support and continued R&D investment, demand for high-performance NdFeB magnets is set to grow rapidly, especially in robotics and automation. Advances in metallurgy, sintering, and supply chain integration will further strengthen China's leadership in rare earth magnet production.

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[34] "Jinli Permanent Magnet Research Report: Leading High-Performance NdFeB Magnetic Material Supplier with Strong Long-Term Growth Potential" [《金力永磁研究报告：高性能钕铁硼磁材龙头，远期成长动能充足》], 2024.

[35] "Will Tesla's Humanoid Robot Core Materials Change?" [《特斯拉人形机器人核心材料或生变？》], Robotics Lecture Hall [机器人大讲堂], Baijiahao, 2024, at https://baijiahao.baidu.com/s?id=1797672200781782294.

[36] "New Materials Industry Development Guide" [《新材料产业发展指南》], Ministry of Industry and Information Technology, National Development and Reform Commission, Ministry of Science and Technology, Ministry of Finance, December 30, 2016, at https://app.www.gov.cn/govdata/gov/201701/23/397855/article.html

[37] "Guiding Catalog for the First Batch Application Demonstration of Key New Materials (2021 Edition)" [《重点新材料首批次应用示范指导目录（2021 年版）》], Ministry of Industry and Information Technology of the People's Republic of China, December 2021, at https://gxt.fujian.gov.cn/zwgk/gsgg/202201/t20220105_5807792.htm

[38] "Analysis of the 2023 NdFeB Market: Sintered NdFeB Raw Material Output Exceeds 230,000 Tons" [《2023 年钕铁硼市场现状分析：烧结钕铁硼毛胚产量超 23 万吨》], Qianzhan Industry Research Institute [前瞻产业研究院], 2023, at https://bg.qianzhan.com/report/detail/300/231128-023a60e8.html.

[39] Ibid.

## High-End Chips and AI

The development of humanoid robots as the ultimate form of AI requires far more than large language models or multimodal AI—it demands high-end chips capable of processing complex sensory inputs, decision-making in real time, and dynamically controlling motion. Unlike software-based AI, which operates in digital environments, humanoid robots must interact with the real world, requiring efficient computing, advanced algorithms, and massive data processing power to function autonomously. The ability to perceive, reason, and act in a human-like manner places extreme computational demands on AI chips, making cutting-edge semiconductor technology a fundamental pillar of robotic AI development.
China's recent advancements in AI, particularly with DeepSeek, demonstrate a leap forward in efficient algorithm design. DeepSeek's ability to optimize model efficiency, data processing, and computational costs makes it an optimal option in the field of robotic AI, where affordability and performance must be balanced. Unlike traditional industrial robots, humanoid robots require precise motor control, adaptive learning, and complex interaction capabilities, all of which depend on motion control units (MCUs) and AI-enhanced system-on-chips (SoCs) to integrate perception, cognition, and execution seamlessly.[40] As humanoid robotics evolve, these AI processors will need to support multimodal learning, predictive decision-making, and real-time environmental adaptation, pushing beyond the capabilities of conventional AI models.

China's efforts to develop AI chipsets, neural network accelerators, and brain-inspired computing reflect its ambition to lead in the AI-driven robotics revolution. As the physical embodiment of AI, humanoid robots will require continuous advancements in hardware efficiency, low-power computing, and high-speed data integration. However, export controls and the systemic lack of high-end chips present significant obstacles that China must overcome during this experimental phase, which demands extensive resources. The U.S. Department of Commerce has introduced comprehensive export controls aimed at weakening China's domestic semiconductor ecosystem, thereby hindering its ability to manufacture advanced chips locally. These restrictions exacerbate the challenges in developing the necessary computational infrastructure for advanced AI applications, including humanoid robotics. Consequently, China faces the critical task of achieving self-reliance in semiconductor production to ensure the sustainable advancement of its AI and robotics industries.

## China's robotics AI ecosystem

China's AI and robotics ecosystem has seen significant growth, with major companies driving innovation in humanoid robotics and embodied intelligence. These firms are pioneering advancements in robotic hardware, AI integration, and industrial automation, positioning China as a leader in next-generation intelligent robotics.

[40] "In-Depth Report on Artificial Intelligence – Robotics Series: Technology Section" [《人工智能深度报告--机器人系列技术篇》], CSDN, 2024

| Company | Key Focus | Notable Product | Key Innovation | Market Strategy |
|---|---|---|---|---|
| **Unitree Robotics (宇树科技)** | Quadruped and humanoid robots | Unitree G1 (2024) - Humanoid robot priced at ¥99,000 with advanced mobility | Pioneering in legged robots, expanding into humanoid robotics | Large-scale deployment in industrial and commercial applications |
| **UBTech Robotics (优必选)** | Humanoid robots for education, logistics, security, and commercial use | Walker S1 - Achieved 25% efficiency improvement, targeting cost reduction below $50,000 by 2025 | First Chinese company to commercialize large-scale humanoid robots | Expanding humanoid robot accessibility through cost reduction |
| **Fourier Intelligence (傅利叶智能)** | Rehabilitation and humanoid robotics | GR-1 (2023) - Human-like mobility with proprietary FSA actuator for optimized motion | Developed in-house FSA actuator for improved power efficiency | Positioning as a leader in China's humanoid robotics sector |
| **Agibot (Zhiyuan Robotics) (智元机器人)** | AI and humanoid robotics | Far Expedition A1 - Features PowerFlow joint motor and SkillHand dexterous hand | Proprietary joint motor and dexterous hand with fingertip vision sensors | Accelerating commercialization in interactive services and manufacturing |
| **Xiaomi Robotics (小米)** | Consumer electronics and robotics | CyberDog (2021), CyberOne (2022), CyberDog 2 (2023) - Advancing AI-powered robots | Integrating AI and cost-effective manufacturing for mass adoption | Leveraging AIoT expertise to scale robotics for mass adoption |

Source: Jamestown's database on PRC's Robotics Ecosystem

Huawei is actively building an ecosystem for embodied AI, integrating large models, edge computing, and robotic intelligence. In November 2024, Huawei (Shenzhen) Global Embodied Intelligence Industry Innovation Center officially commenced operations, aiming to accelerate breakthroughs in humanoid robotics. Huawei has partnered with Leju Robotics, Dazhou Robotics, Tuosida, Zhongjian Technology, and Zhaowei Electromechanical, among others, to drive collaborative innovation in AI-powered robotics.[41] Huawei's expertise in AI chipsets, cloud computing, and machine learning is expected to play a crucial role in advancing humanoid robotic intelligence and real-world applications.

## III. China's Military Robotics

[41] "Huawei (Shenzhen) Global Embodied Intelligence Industry Innovation Center Set to Launch in Collaboration with Qianhai and Bao'an" [《携手前海、宝安，华为（深圳）全球具身智能产业创新中心即将启动运营》], Qianhai Government, 2024, at https://qh.sz.gov.cn/sygnan/qhzx/dtzx/content/post_11734159.html.

**Domestic Drone Development Outlook**

| Year | Milestone Achievement |
|---|---|
| **2022** | Drone technology reaches world-class standards. |
| **2023-2024** | The Army and Air Force begin accelerating drone deployment. |
| **2025** | Establishment of a globally competitive drone system production network. |
| **2035** | Strong independent innovation capabilities to lead global drone industry, meeting world-class military standards. |

Source: "White Paper on Unmanned Aerial System Development (2018)" [42]

**The Strategic Development of Military Drones in China**

The development of military drones in China has been a key strategic priority, aligning with the broader vision of modernizing the country's defense capabilities. President Xi Jinping, during his visit to the Air Force Aviation University on July 23, 2020, emphasized the growing role of unmanned combat systems in transforming modern warfare. He underscored the necessity of strengthening research in unmanned combat, enhancing UAV-related education, and accelerating the training of drone operation and command personnel.[43] These directives have significantly influenced China's UAV (Unmanned Aerial Vehicle) strategy, driving research and development in autonomous aerial combat technologies.

China has laid out an ambitious roadmap for UAV development. According to the Aviation Industry Corporation of China's (AVIC) White Paper on UAV Systems Development published in 2018, the country aims to establish a comprehensive, high-end UAV system by 2025. This system will feature breakthroughs in key technologies, a well-structured industrial ecosystem, and globally competitive production capabilities. Looking ahead to 2035, China's goal is to achieve global leadership in UAV technology, ensuring self-sufficiency in critical defense applications, and positioning itself at the forefront of industrial drone markets. The Air Force has confirmed that China's UAV technology has already reached world-class standards and that further collaboration with the defense industry is underway to develop next-generation UAV platforms.[44]

Military drones have become an essential element in "new domain and new quality" combat forces, leveraging advanced information technology and artificial intelligence for strategic aerial

[42] "White Paper on Unmanned Aerial Systems Development (2018)" [《无人机系统发展白皮书（2018）》], Aviation Industry Corporation of China (中国航空工业集团有限公司), 2018.
[43] "Xi Jinping Emphasizes Deepening Reform and Innovation to Continuously Improve Education Quality During Visit to Air Force Aviation University Before August 1st" [《习近平八一前夕视察空军航空大学时强调 深化改革创新 不断提高办学育人水平》], The State Council of the People's Republic of China, 2020, at https://www.gov.cn/xinwen/2020-07/23/content_5529519.htm.
[44] "White Paper on Unmanned Aerial Systems Development (2018)" [《无人机系统发展白皮书（2018）》], Aviation Industry Corporation of China (中国航空工业集团有限公司), 2018.

operations.[45] As China focuses on long-range precision strikes, intelligent warfare, stealth technology, and unmanned combat, military drone development is receiving strong policy support. The integration of civil-military research collaborations and industrial innovation has further accelerated advancements in China's drone industry, fostering a robust ecosystem for both military and commercial applications.

**Aircraft Platform and Flight Systems**

At the core of any drone is its airframe and aerodynamic design, which dictate structural integrity, maneuverability, and mission adaptability. A drone's layout depends on its operational role, with fixed-wing drones excelling in endurance and speed, while rotorcraft designs provide superior agility and vertical takeoff capabilities.[46] The flight system integrates propulsion, navigation, and onboard control units, forming the backbone of the drone's autonomous flight capabilities.[47]

**Power Systems: The Heart of Drone Performance**

A drone's propulsion system significantly impacts its payload capacity, endurance, altitude, and speed. Propulsion solutions vary across drone classes, ranging from electric motors in micro-drones to advanced turbine engines in high-altitude, long-endurance UAVs.[48] Gas turbine engines such as turbojets and turbofans enable high-speed reconnaissance and combat operations, whereas turbo-prop and piston engines offer extended endurance for surveillance missions. With the increasing need for high-altitude, high-speed drones, the demand for turbojet and ramjet engines is expected to rise, supporting next-generation unmanned combat aircraft.[49]

**Mission Payloads: Intelligence, Surveillance, and Combat Capabilities**

The effectiveness of a drone is largely determined by its mission payloads, which include optical sensors, synthetic aperture radar (SAR), and weaponry. Optoelectronic payloads serve as the "eyes" and "brain" of drones, enabling real-time reconnaissance, target identification, and battlefield situational awareness. Multi-spectral imaging, including visible light, infrared, and laser detection, allows drones to operate effectively in diverse combat environments. Leading Chinese companies such as AVIC Optoelectronics, StarNet YuDa, and Dali

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[45] "A Batch of New Strategic and Advanced Combat Forces Unveiled: 'Major Power Equipment' Showcases 'Hardcore' Strength" [《一批新域新质作战力量最新成果纷纷亮相 "大国重器"展现"硬核"力量》], CCTV (央视网), November 14, 2024, at https://news.cctv.com/2024/11/14/ARTIOBCv1nIVPraEJTswNU7C241114.shtml.

[46] "Basic Knowledge of Drones: Fundamental Components of a Multi-Rotor UAV System" [《无人机基础知识：多旋翼无人机系统基本组成》], CSDN, at https://blog.csdn.net/qq_32761549/article/details/127102797.

[47] "Analysis of Low-Altitude Intelligent Networks and UAV Industry Applications" [《浅析低空智联网与无人机产业应用》], Fan Bangkui (樊邦奎), Li Yun (李云), Zhang Ruiyu (张瑞雨), Progress in Geography [《地理科学进展》], Vol. 40, Issue 9, 2021.

[48] Ibid.

[49] "Building Intelligent Unmanned Flight with 'China Technology'" [《构建智能无人飞行的"中国技术"》], United Aircraft Corporation [联合飞机集团], Total Issue No. 2, July 2022.

Technology specialize in developing high-performance optical pods for reconnaissance and targeting.[50]

**Synthetic Aperture Radar: Overcoming Limitations of Optical Reconnaissance**

SAR technology is crucial for day-night, all-weather battlefield imaging, overcoming the vulnerabilities of optical sensors in adverse conditions. While traditional reconnaissance UAVs rely on infrared and visual cameras, they are limited by poor visibility and atmospheric conditions. SAR-equipped drones offer unparalleled battlefield intelligence, with the ability to penetrate cloud cover and camouflage, making them indispensable for modern warfare. China has made significant strides in miniaturizing SAR payloads for UAV integration, allowing for high-resolution real-time mapping and strategic target acquisition. As UAVs continue to evolve, SAR technology will play a key role in expanding their operational effectiveness across multiple domains.[51]

**Notable Trends**

China's military UAV development follows three major technological trends: stealth, intelligence, and anti-jamming capabilities. The emphasis on stealth technology has led to the adoption of radar-absorbing coatings, infrared suppression materials, and structural modifications that reduce the Radar Cross Section (RCS) and infrared signatures of drones. These advancements enhance survivability in contested environments by improving battlefield concealment and reducing vulnerability to enemy detection and interception. Furthermore, artificial intelligence is playing a crucial role in advancing UAV autonomy.[52] Modern Chinese drones are being developed to execute three primary modes of intelligent combat: autonomous missions, multi-UAV swarm coordination, and human-machine collaborative operations. The increasing use of AI-driven swarm technology allows drones to share real-time data, conduct coordinated attacks, and enhance reconnaissance capabilities. However, achieving full autonomy in combat UAVs remains a challenge that requires sophisticated machine learning and real-time decision-making algorithms. Moreover, military drones must possess robust anti-jamming features to ensure resilience against electromagnetic interference, cyber threats, and electronic countermeasures deployed by adversaries.[53] These capabilities are essential for maintaining operational effectiveness in modern electronic warfare scenarios.

**China's Dominance in Combat Drones and Global Market Expansion**

China has rapidly emerged as a dominant player in the global UAV export market, driven by the high performance and cost-effectiveness of its drone systems. Between 2010 and 2020, China accounted for 17% of global military UAV exports, ranking third after Israel (31%) and the United States (28%). By 2024, China's share in the global military drone market is projected to

[50] Ibid.
[51] Ibid.
[52] "Research on the Development, Application, and Main Combat Patterns of Key Military UAV Technologies" [《军用无人机关键技术发展应用及主要作战样式研究》], Miao Zhuang (苗壮) et al., Flight Missile [《飞航导弹》], September 2020.
[53] Ibid.

rise to 25%, with an estimated market valuation of $4.025 billion.[54] Demand for Chinese UAVs is particularly strong in developing countries across the Middle East, Southeast Asia, and Africa, where cost-effective, high-performance drones provide a viable alternative to Western defense systems.

Among China's most successful UAV platforms, the Wing Loong and CH-series drones stand out as flagship products with widespread global deployment. The Wing Loong series, developed by Chengdu Aircraft Industry Group (CAIG), includes a range of long-endurance reconnaissance and strike UAVs. The Wing Loong-1 was China's first export-oriented medium-altitude long-endurance (MALE) UAV and has been widely deployed in countries such as Pakistan, the United Arab Emirates, Saudi Arabia, and Egypt. The Wing Loong-1D introduced an all-composite design, improving durability and operational performance, while the Wing Loong-2 became China's first turboprop-powered combat UAV, significantly expanding mission range and payload capacity. The CH-series drones, developed by Aerospace CH UAV Corporation, have been China's most commercially successful UAV exports. The CH-4 UAV, known for its affordability and combat efficiency, has set a benchmark for China's UAV exports, with deployments in over ten Belt and Road Initiative (BRI) countries.[55][56]

China's UAV industry is supported by an extensive and vertically integrated supply chain. The upstream segment includes raw materials such as metal and composites, as well as advanced electronic components including avionics and AI chipsets. Midstream players specialize in manufacturing flight platforms and mission payloads, integrating optical sensors, synthetic aperture radar (SAR) systems, and advanced propulsion units. Downstream manufacturers focus on assembling complete UAV systems for military and civilian applications. The industry is dominated by state-owned enterprises such as the Aviation Industry Corporation of China (AVIC). The rapid evolution of China's UAV industry underscores its commitment to achieving technological self-reliance and enhancing global competitiveness. With continued investment in AI-driven flight autonomy, advanced reconnaissance capabilities, and integrated electronic warfare systems, China's drone sector is set to play a pivotal role in shaping the future of unmanned combat and intelligence operations. [57]

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[54] "2011-2021 China's Military UAV Export Models and Quantity Proportions" [《2011-2021 年中国军用无人机出口型号及数量占比》], Everbright Securities Research Institute [光大证券研究所], at https://www.hangyan.co/charts/3028387951395473295.

[55] "Wing Loong-X and Over 20 Domestic Military UAVs Debut at Airshow, UAV Coordination System Becoming More Advanced" [《翼龙-X 等二十余型国产军用无人机亮相航展 无人机协同体系日益完备》], Xinhua News Agency [新华网], November 14, 2024, at https://archive.ph/BDaTg.

[56] "China's Increasing Global Drone Footprint" [China's Increasing Global Drone Footprint], Dr. Abhishek Kumar Darbey, Institute for Defence Studies and Analyses (IDSA), 2024, at https://www.idsa.in/publisher/comments/chinas-increasing-global-drone-footprint/.

[57] "Comparison of Chinese and American Drones and Their Implications" [《中美无人机对比及其启示》], He Jiangyan (何江彦), Zuo Xianzhang (左宪章), Zheng Yijie (郑翌洁), China Modern Educational Equipment [《中国现代教育装备》], 2020.

**Military Robotics: Quadrupedal Robotic Dogs**

The emergence of quadrupedal robotic dogs marks a significant advancement in military robotics, offering unique operational advantages in reconnaissance, battlefield engagement, and logistical support. These four-legged robotic platforms are designed to maneuver diverse terrains with high mobility, performing actions such as advancing, lying down, jumping, and retreating. Equipped with AI-powered navigation systems, they can autonomously map their surroundings, avoid obstacles, and engage in mission-specific tasks, making them a crucial asset in modern warfare.[58]

China has made significant strides in the development of quadrupedal robotic dogs, rapidly advancing their capabilities for military applications. The integration of artificial intelligence enables these robotic platforms to autonomously identify targets, determine optimal engagement timing, and adjust movement patterns based on real-time battlefield conditions. The versatility of these robotic dogs allows them to conduct reconnaissance missions by transmitting real-time intelligence to command centers, execute direct combat roles by carrying rifles or other weaponry, and assist in command-and-control operations by managing logistical support and tactical coordination.

China's rapid progress in this field was demonstrated at the 2022 Zhuhai Airshow, where China North Industries Corporation (Norinco) 58 Institute unveiled its independently developed quadrupedal robotic system. This robotic dog exhibited high maneuverability, heavy payload capacity, and multi-terrain adaptability, making it suitable for reconnaissance, fire suppression, cooperative assaults, hazardous material handling, and supply transportation.[59] The latest iteration of this robotic platform was showcased again in 2024 during the Sino-Cambodian "Golden Dragon" joint military exercises, highlighting its enhanced reconnaissance and combat functionalities. The reconnaissance variant of this robotic dog is lightweight and agile, equipped with LiDAR sensors and cameras for intelligence gathering, while the combat variant, weighing approximately 100 pounds, can be armed with automatic rifles and other weaponry, operated remotely by military personnel.[60]

At the 2024 Zhuhai Airshow, Norinco 58 Institute further unveiled an advanced quadrupedal robotic team under the "Machine Wolf" program, featuring modularized robotic units specializing in distinct battlefield roles. The reconnaissance Machine Wolf gathers intelligence through optical and infrared sensors, the logistics Machine Wolftransports ammunition and supplies, and the precision strike Machine Wolf utilizes real-time data to engage targets with

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[58] "CCTV Exposes PLA Exercise: Tanks and Robot Dogs Deployed, A Wake-Up Call for U.S. Military on the Island"[《央视曝光解放军演习：坦克和机器狗集体出动，美军给岛内提了个醒》], Baijiahao, 2025, at https://baijiahao.baidu.com/s?id=1821912177769225156.

[59] "AI Empowering the Defense Industry as a New Trend, Ground Robots Expected to Enter Combat First" [《AI 赋能军工成为新趋势，地面机器人有望率先走向实战》], Baijiahao, 2025, at https://baijiahao.baidu.com/s?id=1819222659499380264.

[60] "One Step Ahead of the U.S.!' U.S. Media Claims PLA's Robot Dogs Have Become Urban Warfare Weapons"[《"领先美国一步！"美媒称解放军机器狗成巷战利器》], Xinhua News Agency [新华网], 2024, at http://www.xinhuanet.com/mil/2024-05/27/c_1212366008.htm.

mounted firearms.[61] This modular organization enables high levels of autonomous coordination and intelligent decision-making, demonstrating China's increasing sophistication in AI-driven robotic warfare.

China North Industries Corporation (Norinco) has played a leading role in these developments. Originally established as the 58th Research Institute in 1977, the organization underwent restructuring and is now a key subsidiary of China North Industries Group Corporation Limited. The company has set forth a strategic mission of enhancing weapon system intelligence and battlefield automation, positioning itself as a major force in the mechanization, informatization, and intelligentization of Chinese defense systems.[62]

Another major contributor to China's military robotics sector is Chongqing Jianshe Industry (Group) Co., Ltd., a key subsidiary of China South Industries Group Corporation, one of China's largest defense manufacturers. As part of its expansion into military robotics, Chongqing Jianshe showcased a fully weaponized heavy quadrupedal robotic dog at the 2024 Zhuhai Airshow, emphasizing its strategic focus on integrating robotics with advanced firepower systems.[63]

China's military robotics sector is also witnessing increasing participation from private enterprises, driving innovation and competition within the defense industry. Companies like Beijing Jingpin Special Equipment (晶品特装) and Beijing Emerging Equipment Technology (新兴装备) have become key suppliers of specialized reconnaissance and combat robotics. The former has successfully developed a range of military robots and optical sensor systems that have been integrated into frontline military units and special operations forces.64 The latter is a high-tech enterprise focused on unmanned aerial systems, electromagnetic weaponry, and advanced aviation technology, providing AI-driven weapon integration solutions for China's defense sector.[65] China's advancements in quadrupedal robotic dogs and battlefield AI systems reflect its broader goal of achieving technological dominance in intelligent

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[61] "From 'Robot Dogs' to 'Robot Wolves': These Adorable Machines Can Now 'Fight in Teams'!" [《"机器狗"到"机器狼"，这些呆萌的家伙能"打团战"了！》], Hunan Daily [湖南日报], 2024, at https://baijiahao.baidu.com/s?id=1815752284527659269.

[62] "Research on the Development, Application, and Main Combat Patterns of Key Military UAV Technologies" [《军用无人机关键技术发展应用及主要作战样式研究》], Miao Zhuang (苗壮) et al., Flight Missile [《飞航导弹》], September 2020.

[63] "Chongqing Construction Industry Group Showcases Robot Dogs to Foreign Militaries at the 2024 Zhuhai Airshow" [《2024年珠海航展上重庆建设工业集团机器狗向外军进行动态展示》], Bilibili, 2024, at https://www.bilibili.com/video/BV1sdzmYEEUX/

[64] "Beijing Jingpin Special Equipment Technology Co., Ltd. Official Website" [《北京晶品特装科技股份有限公司官方网站》], Beijing Jingpin Special Equipment Technology Co., Ltd. (晶品特装), at https://jp-tz.com/gsjj.

[65] "Beijing Emerging Eastern Aviation Equipment Co., Ltd. Company Profile" [《北京新兴东方航空装备股份有限公司公司简介》], Beijing Emerging Eastern Aviation Equipment Co., Ltd. (新兴装备), at https://www.qcc.com/product/1927ba7a-6a6b-4380-b823-2d6823231d10.html.

warfare. With an increasing focus on machine autonomy, networked warfare, and AI-driven battlefield analytics, China is positioning itself as a leader in the next-generation military robotics revolution.

**Undersea Robotics: Autonomous Unmanned Underwater Vehicles (UUVs) and Military Applications**

The development of undersea robotics is a critical aspect of China's "Made in China 2025" (MIC 2025) strategy, which seeks to advance high-tech industries, including autonomous manufacturing, deep-sea exploration, and naval defense. Unmanned Underwater Vehicles (UUVs) and Autonomous Underwater Vehicles (AUVs) serve dual-use purposes, supporting marine research, deep-sea resource exploration, undersea infrastructure maintenance, and military operations. These systems provide China with strategic advantages in maritime surveillance, anti-submarine warfare, and mine countermeasures, aligning with national objectives to establish a stronger maritime defense system.[66]

China's UUV development has expanded rapidly, with a growing focus on deep-diving endurance, AI-driven autonomy, and enhanced sensor capabilities. The Haiyan underwater glider (海燕), developed by Shanghai Jiao Tong University, can operate autonomously for over 200 days, reaching depths of 1,000 to 1,500 meters, making it a key asset for long-duration oceanographic monitoring. The HSU-001 UUV, unveiled during the 2019 National Day Parade, showcases China's advancements in military-grade undersea drones, potentially designed for reconnaissance, anti-submarine warfare, and underwater combat support.[67]

China's UUV advancements have been driven by leading state-owned defense conglomerates, particularly China Shipbuilding Industry Corporation (CSSC) (中船重工). CSSC, as the largest shipbuilding enterprise in China, is spearheading the development of large-displacement UUVs (LDUUVs) and undersea surveillance systems. Groups in the industry work on improving UUV stealth, endurance, and multi-mission adaptability, critical to China's long-term naval strategy.[6869]

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[66] "The 'Dark Horse' Entering the Underwater Battlefield: Unmanned Underwater Vehicles" [《闯入水下战场的"黑马"：无人潜航器》], China Military Online – PLA Daily [中国军网-解放军报], April 2024, at http://www.81.cn/yw_208727/16303868.html.

[67] "Current Research Status and Prospects of Unmanned Underwater Vehicles" [《水下无人航行器的研究现状与展望》], Armed Police Research Institute [武警研究院], December 2023.

[68] "Global Research Frontiers Identification and National Development Layout of Underwater Vehicles" [《水下潜器全球研发前沿识别与国家研发布局》], Wang Yunfei (王云飞), Wang Zhiling (王志玲), Song Wei (宋伟), Chu Zhiyong (初志勇), Xue Zhao (薛钊), 2022.

[69] "The 'Dark Horse' Entering the Underwater Battlefield: Unmanned Underwater Vehicles" [《闯入水下战场的"黑马"：无人潜航器》], China Military Online – PLA Daily [中国军网-解放军报], April 2024, at http://www.81.cn/yw_208727/16303868.html.

While China has successfully demonstrated UUV prototypes, the mass deployment and integration of these systems into naval fleets remain an ongoing challenge. Underwater docking, extended mission autonomy, and real-time data transmission are areas where further technological advancements are required. Given the increasing geopolitical tensions in the South China Sea and Pacific region, China is accelerating UUV deployment for naval superiority. Efforts to establish a networked underwater Great Wall, integrating UUV surveillance systems, deep-sea listening arrays, and AI-driven reconnaissance platforms, highlight the strategic importance of underwater autonomous warfare in China's defense strategy.

## IV. Challenges Facing China's Robotics Industry

China's robotics industry has seen remarkable progress, driven by national policies such as Made in China 2025, rapid industrial automation, and advancements in AI-driven robotics. However, despite these achievements, the sector faces several challenges that could slow its progress and limit its competitiveness in key global markets.

### High Costs and Material Limitations in Lightweight Robotics

One of the biggest technological and economic challenges in China's robotics industry is the high cost of lightweight materials, which is essential for improving energy efficiency, reducing operational costs, and expanding robotic applications. Lightweight robotics are particularly critical for autonomous service robots, medical robotics, and space applications, where reducing weight directly enhances mobility, energy consumption, and safety.

One of the most promising materials considered by China for lightweight robotics is PEEK (Polyether ether ketone) (聚醚醚酮), a high-performance engineering plastic that combines low density, high strength, corrosion resistance, and excellent mechanical properties. PEEK offers the potential for replacing steel in industrial applications, significantly reducing robot weight while maintaining durability.[70]

However, China remains dependent on foreign imports for high-quality PEEK production, with leading global manufacturers such as Victrex (United Kingdom), Solvay (Belgium), and Evonik (Germany) dominating the market. Chinese companies, PanJin Zhongrun (盘锦中润) and Jilin Zhongyan (中研高能), are catching up behind.[71] If China cannot be self-sufficient in this area, its robotics industry may struggle to meet the demands of high-mobility applications, including surgical robots, humanoid robots, and space-exploration robotics, where weight is a critical factor in efficiency and performance.

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[70] "Humanoid Robot Industry Sees Rapid Growth, PEEK Material Demand Expected to Surge" [《人形机器人产业迎来密集催化，PEEK 材料需求增速有望更趋陡峭》], Baijiahao, 2025, at https://baijiahao.baidu.com/s?id=1822089006710581172.

[71] "Polyetheretherketone (PEEK) Market Size Expected to Hit USD 1.7 Billion by 2034 with a 7.4% CAGR Increase" [Polyetheretherketone (PEEK) Market Report], Transparency Market Research, 2024, at https://www.globenewswire.com/news-release/2024/09/27/2954741/0/en/Polyetheretherketone-PEEK-Market-Size-Expected-to-Hit-USD-1-7-Billion-by-2034-with-a-7-4-CAGR-Increase-Exclusive-Report-by-Transparency-Market-Research-Inc.html.

## Dependence on Foreign High-End Components and Industrial AI

Despite its rapid advancements in AI and automation, China remains reliant on foreign-made high-end components for industrial and humanoid robots, particularly in precision actuators, high-torque servo motors, AI processors, and advanced sensors. The domestic supply chain for robotic intelligence and industrial AI chips is still in its early stages, and companies continue to import key components from Japan, Europe, and the United States.

The lack of a fully independent AI and semiconductor ecosystem hinders China's ability to scale robotic intelligence and autonomy. AI-driven robotics require powerful computing infrastructure to process vast amounts of real-time data, enabling functions such as visual recognition, movement prediction, and autonomous decision-making. While China has made strides with AI companies like DeepSeek and Huawei Ascend AI, a handful of "unicorn enterprises" are still unmatched to the U.S. broad ecosystem. A well-executed U.S. export controls on high-end GPUs, AI chips and potential legacy chip can significantly limit China's ability to train advanced robotics models in a long run.

## The Industrial Robotics Gap

While China is the world's largest market for industrial robots, its domestic robotics industry is still underdeveloped in key areas, particularly in high-end automation and humanoid robotics. A significant portion of China's industrial robots are low-tech mechanical arms focused on simple tasks such as material handling (55%) and welding (25%), with relatively low precision and intelligence.[72] China's industrial robots are thus not yet capable of fully addressing its aging workforce crisis, which is expected to severely impact economic productivity in the coming decades. The country's rapidly shrinking labor force necessitates a large-scale shift to automation, but current industrial robotics adoption remains highly concentrated in automotive manufacturing and electronics assembly.

Another major challenge is the development of mobile industrial robots, such as AGVs (Automated Guided Vehicles) and ACRs (Autonomous Case-handling Robots), which have grown rapidly but still lack advanced AI-driven decision-making capabilities. It remains to be seen whether China can make a leap in industrial AI and eventually deploy it at scale to offset labor shortages.

## PLA Decision-Making Challenges in Autonomous Military Robotics

One of the most profound challenges facing China's military robotics development is the structural conflict between centralized PLA decision-making and the real-time autonomy required for advanced AI-driven combat platforms. The PLA operates under a highly centralized command structure, emphasizing strict hierarchical control. While this system ensures political oversight and coordination, it is fundamentally at odds with the core advantage of AI-driven

[72] "2022 China Industrial Robot Market Research Report" [《2022 中国工业机器人市场研究报告》], EO Intelligence [亿欧智库], 2022

autonomous warfare—the ability to process battlefield data and make split-second tactical decisions faster than human operators.

Autonomous military platforms, such as AI-powered drones, robotic infantry units, and swarm-based warfare systems, require a level of decision-making independence that the PLA may be unwilling to grant. The PLA's reluctance to fully delegate combat decisions to AI systems could limit the effectiveness of its autonomous weapons programs.

However, this concern may be mitigated over time through continuous military drills, real-world data collection, and AI model refinement. By conducting large-scale military exercises, the PLA can improve its ability to integrate AI-assisted decision-making into its command structure, allowing for greater trust in autonomous systems while maintaining strategic oversight.

## V. China's Autonomous Dominance: Future Economic and National Security Challenges for the United States and Its Allies

China's rapid advancements in autonomous technologies pose profound economic and national security challenges to the United States and its allies, reshaping the balance of power in AI-driven warfare, autonomous combat systems, and strategic defense technologies. As China aggressively invests in robotic AI, intelligent combat systems, and cost-effective military automation, it challenges U.S. technological superiority while increasing its global defense influence.

### The Rise of Humanoid Robotics and "Physical AI" Leadership

The future of AI is physical—a concept endorsed by industry leaders, who argue that humanoid robotics and embodied AI represent the ultimate evolution of artificial intelligence, far beyond the current capabilities of LLMs (large language models) and multimodal AI. While chatbots and digital assistants have revolutionized information processing, the next frontier is AI-powered physical automation, where humanoid robots replace human labor across industries, defense, and logistics.

China has positioned itself at the forefront of humanoid robotics, surpassing global competitors in production, deployment, and market influence. Companies like UBTech, Fourier Intelligence, Xiaomi, and Unitree Robotics have not only pioneered humanoid robot development but also established dominant market shares in both commercial and industrial robotics. As the demand for autonomous labor surges, downstream customers—including logistics, manufacturing, medical, and security sectors—are increasingly dependent on Chinese robotics solutions, limiting alternative suppliers for Western economies.

From a military standpoint, humanoid robots will play an essential role in next-generation warfare, acting as autonomous battlefield units, logistics operators, and AI-driven combat assistants. These machines are highly mobile, adaptable to unpredictable environments, and capable of executing complex military tasks, making them a crucial force multiplier in future conflicts. If China maintains its leadership in humanoid robotics, the U.S. risks falling behind in

both military automation and AI-driven economic transformation, further weakening its industrial and defense capabilities.

**AI-Enabled Warfare: Battlefield Autonomy and Decision Superiority**

China's integration of AI-driven decision-making systems into operations is reshaping its military. The development of battlefield intelligence networks, autonomous mission planning, and predictive combat analytics enables China's military to process real-time data, anticipate enemy movements, and automate strategic decisions at speeds unmatched by traditional command structures.

China is actively developing AI-powered war-gaming simulations, where machine learning algorithms train on real-world combat data, continuously improving tactical coordination between human soldiers, UAVs, and robotic combat units. This autonomous battle management system gives China the ability to coordinate large-scale military operations with minimal human intervention, drastically improving combat efficiency.[73]

Unlike the U.S., which predominantly manufactures high-end military UAVs, China produces a full spectrum of drones, ranging from low-cost, expendable UAVs to microdrones and sophisticated, stealth-capable combat drones. Also, China's integrated reconnaissance-strike UAVs, such as the Wing Loong II and CH series, directly compete with U.S. MQ-9 Reapers, but at a fraction of the cost.[74] This diversified portfolio provides greater operational flexibility, allowing China to experiment with new combat doctrines.

**Unmanned Combat Drones and Swarm Warfare**

China's growing dominance in unmanned aerial vehicles (UAVs) poses both economic and military threats to the United States. The development of low-cost, high-performance UAVs like the Wing Loong and CH series has allowed China to flood the global defense market, providing cost-effective alternatives to U.S. and Israeli drone systems. Countries that cannot access U.S. military technology due to export restrictions increasingly turn to China, strengthening its geopolitical influence and eroding U.S. military alliances.[75] [76]

Beyond traditional drones, China's rapid advancements in UAV swarming technology create a new asymmetric threat against the U.S. and its allies. Swarm tactics enable hundreds of AI-

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[73] "What's 'New' in New-Domain and New-Quality Combat Forces?" [《新域新质作战力量"新"在哪里》], Ministry of National Defense (MND), 2022, at https://archive.ph/nuS4D#selection-215.0-215.14.

[74] "Analysis of U.S.-China UAV Development" [《中美無人機發展評析》], Lin Zongda (林宗達), International Military Affairs Magazine Publishing House [國際軍務雜誌社], 2024.

[75] "Research on Manned/Unmanned Aerial Vehicle Cooperative Combat Modes and Key Technologies" [《有人/无人机协同作战模式及关键技术研究》], Sun Shengzhi (孙盛智) et al., Aviation Weaponry [《航空兵器》], October 2021

[76] "Research on the Composition and Operational Concepts of Drone Swarm Warfare" [《无人机蜂群作战构成及作战概念研究》], Yang Lina (杨丽娜) et al., Modern Defense Technology [《现代防御技术》], August 2020

coordinated drones to perform synchronized reconnaissance, electronic warfare, and precision strikes, overwhelming enemy defenses, including U.S. naval assets in the Indo-Pacific. These swarms could be weaponized against aircraft carriers, military bases, and strategic installations, reducing the effectiveness of traditional missile defense systems.

**Economic and Strategic implications for the U.S. and Its Allies**

China's dominance in autonomous technology extends beyond military threats, posing economic and strategic risks. Its leadership in AI, robotics, and drones is reshaping industries, reducing U.S. influence, and creating supply chain dependencies on Chinese infrastructure. As China exports these technologies globally, U.S. and allied economies risk long-term reliance on Chinese AI and automation. Cybersecurity concerns further escalate as China's AI-driven surveillance and cyber warfare capabilities threaten global infrastructure. The potential for AI-enabled espionage, cyberattacks, and electronic warfare raises national security risks beyond traditional battlefield applications. If unchecked, China's technological rise could outpace the U.S. in both military and economic domains. To counter this, the U.S. must accelerate investments in AI warfare, autonomous robotics, and cybersecurity to maintain its strategic and technological edge.

## VI. Recommendations for U.S. Policymakers

1. **To counter China's systematic advancements in robotics, the U.S. government should establish a National Robotics Strategy Committee.** Modeled after previous AI and Biosecurity task forces, to coordinate interagency efforts and align national policies with industrial expertise. Given China's dominance in robotic and autonomous technologies, it is critical that the U.S. government fully understands the complex ecosystem of key components, supply dependencies, and industrial capabilities in both industrial and military robotics. The new committee can -

- Map out the robotic supply chain, identifying domestic vulnerabilities in steel alloys, lightweight materials (e.g., PEEK, carbon fiber, magnesium), AI-driven control chips, actuators, precision motors, sensors (IMU, torque, vision, force), battery systems, and high-end semiconductors.
- Analyze global dependencies and monitor key Chinese robotics firms, including actuator manufacturers, gear reducers (e.g., harmonic drives), industrial motors, robotic vision processors, and AI chips, to mitigate reliance on adversarial supply chains.
- Engage with industry leaders and academia to guide U.S. industrial policy, working with leading robotics firms, industrial automation leaders, semiconductor companies, and material science firms to advance domestic robotics capabilities.
- Recommend investment and export control measures to onshore critical manufacturing, restrict Chinese access to sensitive AI-driven robotic technologies, and support trusted suppliers in allied nations (e.g., Japan, South Korea, Germany).

2. **To effectively respond to China's technological and economic advancements, the U.S. government should establish a dedicated Open-Source Intelligence (OSINT) Agency**. It should focus on training experts who understand the Chinese languages and

social context to track, analyze, and predict global technological developments, particularly in robotics, AI, and autonomous military platforms. Given that much of China's progress in these fields is documented in state media, research papers, industrial reports, patents, supply chain data, and investment disclosures, a dedicated OSINT agency would leverage publicly available data to provide timely, strategic insights for policymakers and industry leaders.

- The agency should systematically track China's industrial policies (e.g., MIC 2025, Five-Year Plans), defense-related AI and robotics advancements, corporate strategies, and academic research to assess their long-term impact on U.S. competitiveness and national security.
- The agency should map out the origins of key technologies—such as high-end semiconductors, AI processors, robotic actuators, industrial sensors, autonomous military vehicles, and advanced materials—to identify U.S. vulnerabilities and potential leverage points in global trade.
- The agency would inform export control decisions, investment screening policies (CFIUS), and sanctions on adversarial firms. It could also help coordinate allies' responses to China's state-backed industrial dominance.
- The agency should integrate AI-driven data mining, NLP (natural language processing), and predictive analytics to efficiently process and extract insights from millions of patents, corporate reports, academic papers, trade data, and financial disclosures.
- The agency should help U.S. tech firms, venture capital and academia translate unclassified intelligence insights into actionable policies, ensuring that America's tech ecosystem remains competitive against China's industrial model.

3. **The U.S. must accelerate its adoption of AI-powered warfare technologies to prevent strategic disadvantages.** China is developing PLA-integrated AI warfare systems, including swarm UAVs, autonomous undersea drones (UUVs), and AI-driven battlefield analytics. The U.S. must accelerate its adoption of AI-powered warfare technologies to prevent strategic disadvantages and prioritize AI-integrated warfare research on autonomous decision-making in combat scenarios. The US should continue to enhance AI-augmented military drills to test human-AI coordination in real-world combat scenarios, refining AI decision-making algorithms.

4. **The U.S. should expand export controls to restrict China's access to high-performance AI accelerators, robotic control systems, and dual-use AI software.** China's autonomous military vehicles, humanoid robots, and AI-driven decision systems rely heavily on foreign semiconductor imports and AI chips. The U.S. should expand export controls to restrict China's access to high-performance AI accelerators, robotic control systems, and dual-use AI software. The U.S. should preemptively expand the U.S. Entity List to cover Chinese robotics and AI firms developing autonomous weapons, and work with Japan, South Korea, and the EU to tighten AI chip and robotics export restrictions, preventing China from bypassing U.S. sanctions.

5. **The U.S. must offer strategic alternatives to prevent countries from becoming dependent on Chinese autonomous systems.** China is aggressively exporting UAVs, robotic combat platforms, and AI-driven surveillance technologies to developing nations, expanding its military influence in Africa, the Middle East, and Southeast Asia. The US should expand U.S. defense technology exports to offer allies competitive alternatives to Chinese UAVs and autonomous weapons, and increase foreign military aid for AI-powered defense systems, ensuring allies can counter Chinese-made drone swarms and robotic combat units.

Appendix. China's Provincial Robotics Development Policies in 2024

| Policy Name | Issuing Authority | Goals | Key Tasks |
|---|---|---|---|
| Jiangsu Province Robotics Industry Innovation Development Action Plan | Jiangsu Provincial Department of Industry & Information Technology | Achieve globally advanced industry standards | Enhance innovation capacity, accelerate core technology breakthroughs, and improve industrial foundations |
| Shandong Province Humanoid Robotics Industry Innovation Development Plan (2024-2027) | Shandong Provincial Department of Industry & Information Technology | Significant technological advancements, fostering 10 key enterprises with over 1 billion RMB in revenue | Accelerate technological innovation, strengthen product supply, and promote industrial ecosystem development |
| Shanghai Industrial & Service Industry Upgrade Action Plan (2024-2027) | Shanghai Municipal Government Office | Establish a National Humanoid Robotics Manufacturing Innovation Center and develop robotics production solutions | Create humanoid robotics-enabled manufacturing application scenarios |
| Zhejiang Province Humanoid Robotics Industry Innovation Development Plan (2024-2027) | Zhejiang Provincial Department of Economy & Information Technology | Cultivate 5+ high-level provincial innovation centers and 30 enterprise R&D institutions | Enhance supply chain integration, foster industry clusters, and diversify application scenarios |
| Chongqing Policies for Embodied AI & Robotics Industry Innovation | Chongqing Economic & Information Technology Commission | Advance key technologies, including integrated compute-storage chips and high-performance actuators | R&D focuses on integrated compute-storage chips, new sensors, and robotics operating systems |

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|---|---|---|---|
| Anhui Province Humanoid Robotics Industry Development Plan (2024-2027) | Anhui Provincial Department of Industry & Information Technology | Develop the '23456' humanoid robotics innovation system and industrial ecosystem | Optimize full-machine manufacturing, strengthen advantages, address weaknesses, and build a sustainable ecosystem |