

人形机器人 应用与发展前瞻

中国联合网络通信有限公司研究院
金砖国家未来网络研究院 (中国·深圳)

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目 录

前 言.....	I
编 组.....	II
一、人形机器人发展新态势.....	1
（一）人形机器人发展现状.....	1
（二）全球人形机器人市场前景广阔.....	3
二、人形机器人的技术演进.....	6
（一）整机“智能化感知决策水平”不断提升.....	6
（二）多模态模型算法赋能“大脑”层级进步.....	7
（三）小脑模型算法迭代优化，实现拟人化运动控制.....	7
（四）“肢体”构筑机器人的“钢铁之躯”.....	8
三、全球人形机器人的典型实践与探索.....	10
（一）人形机器人率先重构工业制造人机协同范式.....	11
（二）人形机器人探索构建普惠、精准、有温度的医疗未来.....	12
（三）人形机器人将重塑交通物流生产力范式.....	13
（四）人形机器人将重构家庭生活的效率与体验.....	14
四、探索人形机器人未来发展新路径.....	16
（一）筑牢硬件根基，推动人形机器人产业标准互通.....	16
（二）强化感知能力，促进人形机器人技术融合创新.....	17
（三）聚焦重点场景，驱动人形机器人应用健康发展.....	18

前言

人形机器人作为人工智能与物理世界深度融合的前沿范式，正成为智能技术突破虚拟边界的关键支点。人形机器人打破传统人工智能的“离身认知”局限，通过独特的“人形”设计，使人工智能系统能够无缝适应人类工作与生活环境，熟练操作为人类设计的工具与设备，实现从纯粹信息处理到与物理世界通用交互的本质跨越，为人工智能提供了理解和改造物理世界的最佳“身体”，进而实现真正的“知行合一”。我们将聚焦人形机器人产业发展的前瞻和最新趋势，深度洞察这一技术的应用探索与未来图景，希望可以助力人形机器人产业的高质量发展。

编写组

组长：

李红五 中国联合网络通信有限公司研究院

陈辉 金砖国家未来网络研究院（中国·深圳）

副组长：

杨锦洲 中国联合网络通信有限公司研究院

张阳 中国联合网络通信有限公司研究院

工作组成员：

郭耀隆 中国联合网络通信有限公司研究院

杨峥 中国联合网络通信有限公司研究院

罗力卓 中国联合网络通信有限公司研究院

夏璠 中国联合网络通信有限公司研究院

薛竞 中国联合网络通信有限公司研究院

韩莹莹 中国联合网络通信有限公司研究院

林桢 金砖国家未来网络研究院（中国·深圳）

李纪超 金砖国家未来网络研究院（中国·深圳）

张雅文 金砖国家未来网络研究院（中国·深圳）

一、人形机器人发展新态势

人形机器人作为融合了人工智能、高端制造等先进技术的革命性突破，以颠覆性创新重塑全球科技竞争格局，加速形成数实融合的新质生产力，催生人机协同的新型生产关系，成为驱动数字经济向自主经济跃迁的核心引擎，为数字经济的可持续发展提供更强韧性。

（一）人形机器人发展现状

1.人形机器人的内涵

人形机器人是一种利用人工智能和机器人技术制造的具有类似人类外观和行为的机器人。人形机器人灵感来源于人类的身体，集仿生学原理和机器电控原理于一体。与普通机器人相比，人形机器人最大的特点是拥有拟人智能能力，可以通过人工智能大模型技术的赋能，实现拟人化的感知、决策、控制能力，实现了智能的飞跃。同时，人形机器人还需要具有拟人的外观，通常由头部、躯干、四肢等部分组成，能够实现模拟人类的行走、抓握等动作。这种类似人类的形态，可以快速融入人类社会，完成具体的任务，通用性和适应性较强。

人形机器人依据其结构与功能特性，可主要分为轮式人形机器人、足式人形机器人以及通用人形机器人。轮式人形机器人采用轮式驱动，搭配机器人手臂与灵巧手，兼具移动能力；足式人形机器人着重腿部运动能力，手部主要用于平衡；通用人形机器人具备双足、双臂、双手及各类感知和人工智能功能，有全面软硬件基础，能适应开放环境中的多任务。

2.人形机器人的发展历程

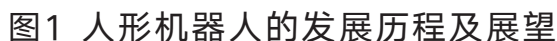
1950年—1980年，为人形机器人的概念萌芽阶段，图灵在其论文中提出了人工智能可能的发展方向，为机器人的概念奠定了基础。现代机器人的雏形是1954年美国麻省理工学院创造的可预编程机械臂。美国通用汽车1960年首次将Unimate工业机器人投入生产线进行焊接工作。斯坦福大学、早稻田大学分别研发了首台移动机器人和可对话的人形机器人。

1980年—2000年，进入早期探索阶段，得益于计算机硬件和传感器设备取得突破，麻省理工学院推出了具有类似人类听觉、视觉和本体感知功能的机器人Kismet。1991年出现了六条腿机器人Genghis，实现了自主行走。

2000年—2010年，进入跨学科融合与技术积累阶段，人形机器人研究开始融合跨学科的方法和技术，如机构学、机器学习、机器人学等，形成了相对完整的学科分支。

2011年—2020年，进入技术突破阶段。深度学习技术的快速发展为其注入了新的发展动力。出现大量仿生、类人机器人，帮助机器人适应自然环境。比如本田的升级版ASIMO机器人能够精确完成抓取物体和倒液体等精细任务，波士顿动力推出的Atlas可以在复杂的户外自然环境中行走、奔跑、跳跃，还能在雪地、草地等不同地形上保持平衡。

2022年至今，为产业应用普及阶段。以ChatGPT为代表的大语言模型为人形机器人实现智能感知、自主决策乃至拟人化交互，正逐步走向产业应用。涌现了宇树、优必选、Figure、Optimus、波士顿动力等一批独角兽企业，推动人形机器人应用深入生产实践。



(来源：中国联通研究院)

（二）全球人形机器人市场前景广阔

1.各国人形机器人战略布局各有侧重

全球主要经济体均高度重视具身智能发展，不断出台政策支持具身智能发展，提升全社会对机器人领域的关注和支持。美国紧抓人工智能基础研究，保持具身智能领域的前沿领先地位。先后出台《国家机器人计划3.0》和《国防部人工智能战略》，将AI技术竞争上升至国家战略层面。欧盟方面，积极推进具身智能发展，强调具身智能的安全与透明度，先后推出《欧盟机器人研发计划》、《欧洲人工智能战略》和《人工智能驱动机器人战略》等。欧盟还以《人工智能法案》为基础，构建了具身智能发展的伦理框架与产业规范。亚洲地区，日本正在将机器人纳入社会并使机器人成为其社会基础的关键部分。2022年日本政府将机器人赋能制造、服务、医疗等应用场景的资金支持提升至1057亿日元。人口老龄化背景下的机器人替代人类是支持重点，推出了《社会基础设施用机器人重点领域》和《服务机器人安全操作国际标准》等政策制度。韩国在机器人产品或服务的技术层面具备一定的实力，但在机器人核心部件或软件技术方面却相对滞后。因此，2008年出台《智能型机器人开发与普及促进法》，2023年发布机器人产业发展战略和《先进机器人监管创新方案》。

2.全球人形机器人市场发展迅速

未来一段时间即将迎来人形机器人高速增长的阶段。从整体规模上看，中国高工机器人产业研究所（GGII）预测，2025年全球人形机器人市场销量有望达到1.24万台，市场规模63.39亿元。到2030年，全球人形机器人市场销量将接近34万台，市场规模将超过640亿元；到2035年，全球人形机器人市场销量将超过500万台，市场规模将超过4000亿元。而高盛预测，到2035年全球范围内人形机器人市场规模有望达到1540亿美元。

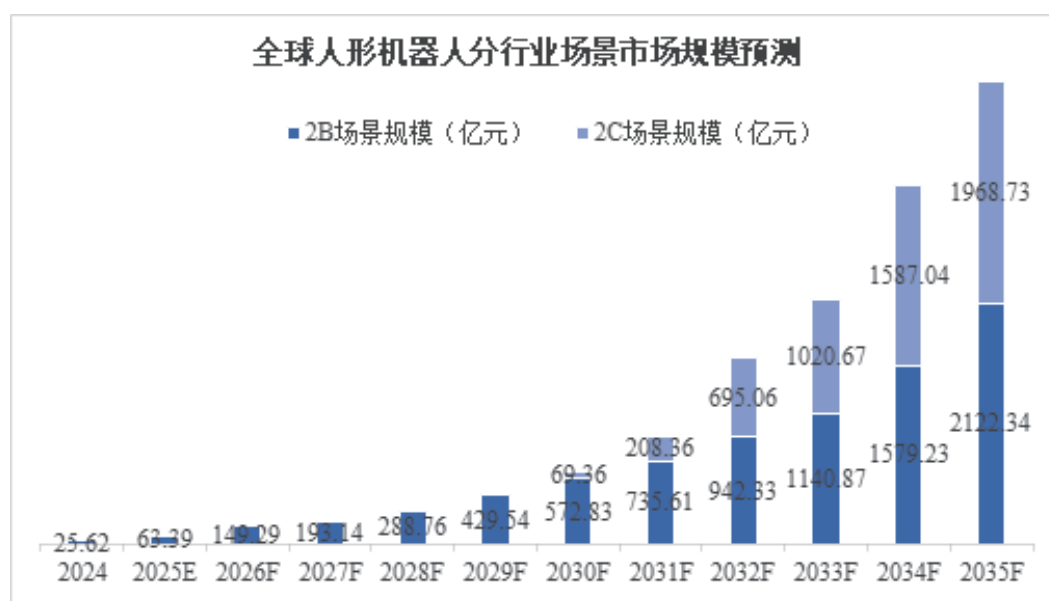


图2 全球人形机器人市场规模及展望

（来源：高工机器人产业研究所）

投融资方面，CB Insights公司数据显示，人形机器人市场2024年融资金额达到了12亿美元的新高，预计今年将达到23亿美元的规模，实现翻一番。

来源：高工机器人产业研究所(GGII)《2025年人形机器人产业发展蓝皮书》

来源：高盛《人形机器人专题报告》



图3 国外企业融资情况概览

（来源：中国联通研究院）

3.各国科技巨头加速推进人形机器人落地实践

全球人形机器人产品已经处于产品发布和应用验证阶段，但到商业落地和大规模量产仍有一段距离。

各国科技巨头已宣布推出多款人形机器人。特斯拉发布“擎天柱”（Optimus）二代的人形机器人。2024年6月，Optimus二代已经被应用在特斯拉工厂，进行电池的分拣训练。波士顿动力（Boston Dynamics）发布了人形机器人Atlas，同样在汽车工厂得到应用，实现汽车支柱搬运等工作。敏捷机器人公司（Agility Robotics）发布了人形机器人Digit。Digit可以实现搬运货物、码垛、卸载等仓库日常工作，在GXO、亚马逊公司已经得到应用。独角兽企业Figure AI通过OpenAI大模型赋能人形机器人，推出Figure 02机器人，能完成叠衣服、餐桌清理、购物袋包装等相对复杂任务，并在宝马汽车工厂中测试开展零件装配等工作。优必选推出Alpha和Walker系列机器人，为教育、物流、消费及其他产业定制，是全球合作车厂最多的人形机器人企业。杭州宇树推出的Unitree H1、Unitree G1人形机器人性能佳、价格低，可用于工业、家庭服务等多重场景。

来源：中金公司《具身智能：AI下一站》

二、人形机器人的技术演进

（一）整机“智能化感知决策水平”不断提升

在全球人形机器人领域，特斯拉、Figure AI、波士顿动力处于第一梯队，1X、Digit等欧美产品紧随其后。这些企业在硬件上追求轻量化、高自由度，软件上借助AI大模型实现多模态感知与推理，部分产品已进入场景测试阶段，展现了人形机器人在工业生产、民生服务、特种作业等多元场景的应用潜力，预计2025年将成为人形机器人的量产元年。

特斯拉Optimus系列展现了快速迭代能力。2022年10月发布Optimus Gen1身高173cm，重73kg，搭载汽车级FSD系统，凭借28个身体自由度和11个手部自由度实现基础运动功能。2023年Gen2实现重大突破，重量降至63公斤，步行速度提升30%，新增颈部自由度显著增强平衡性，可应对爬楼梯等非平坦地形；其配备触觉传感器的灵巧手能精准抓取鸡蛋等易碎物。该系列计划于2026年以2万-3万美元量产，目标覆盖工厂、物流及家庭服务场景。

波士顿动力Atlas作为行业运动能力标杆，2024年推出电动版新款Atlas机器人，具备三指灵巧手，可搬运14kg物体，能完成行走、跳跃、爬楼梯等复杂动作。核心技术模型预测控制器（MPC）推动其从预设动作向自主路径规划进化，在复杂地形运动中保持卓越稳定性，持续拓展运动控制与感知技术的边界，主要服务于科研验证领域。

宇树科技代表中国创新力量。2023年H1搭载自研M107关节电机，单腿自由度设计使其在负重30公斤或外力冲击下稳定运动，3D激光雷达实现360°环境感知。2025年G1转向轻巧化，23-43关节电机支持单腿跳跃等高阶动作，三指灵巧手结合多传感器适应复杂地形，由世界模型UnifoLM驱动的自主学习能力瞄准救援与人机协作应用。

来源：全球人形机器人技术演进趋势.2025年5月29日.https://mp.weixin.qq.com/s?__biz=MzU2MTg0NjE0Mg==&mid=2247591656&idx=1&sn=e0eeac7b407d687cea6ef014b68e26f8#:~:text=o%E8%83%BD%E8%80%97%E4%BC%98%E5%8C%96,%E5%B7%A5%E4%B8%9A%E5%9C%BA%E6%99%AF%E9%AA%8C%E8%AF%81

来源：宇树科技官网.<https://www.unitree.com/>

（二）多模态模型算法赋能“大脑”层级进步

1. 大模型是机器人“大脑”最为理想的选择

人形机器人“大脑”技术以大模型为核心，提供任务交互、环境感知、任务规划及决策控制能力。需具备四大关键能力，实时交互能力，能与人类进行任务级交互；多模态感知能力，整合多感官信息；自主可靠决策能力，分解复杂任务；涌现和泛化能力，在新环境执行任务。

2. 多模态大模型技术发展呈现多元路径共存的演进趋势

从技术路线演进看，基于大模型的机器人“大脑”正沿着四条并行路径向端到端智能发展。其一，LLM+VFM融合路线，最成熟方案。以谷歌SayCan为代表，通过预训练技能的价值函数与大语言模型对齐，将用户指令分解为可执行任务链，实现交互与规划闭环。其二，视觉-语言模型（VLM）路线，重点弥合语言与视觉语义鸿沟。例如清华大学CoPa模型，利用GPT-4V等基础模型的常识知识，生成任务导向的抓取姿态及运动规划方案。其三，视觉-语言-动作模型（VLA）路线，在VLM基础上增加运动控制层。典型代表谷歌RT-H，通过多任务数据集联合训练语言-视觉-动作模块，学习自适应动作策略以解决轨迹决策问题。其四，多模态大模型路线，未来主导方向。如MIT与IBM的MultiPY，融合视觉、触觉等3D环境特征，通过多视图关联构建以对象为中心的场表征，实现全维度环境感知与决策。

（三）小脑模型迭代优化，实现拟人化运动控制

1. “小脑”运动控制路线：基于模式和基于学习

“小脑”运动控制是实现人形机器人自然流畅动作的关键，主要分为基于模型和基于学习两类方法。前者通过建立运动学和动力学模型进行规划控制，如ZMP、混杂零动态规划等算法，但开发复杂、成本高；后者借助人工智能技术，以人类示教（模仿学习）或自主探索（强化学习）建立策略，能降低开发难度、加快迭代。二者各有优劣，共同推动人形机器人运动控制技术发展。

2. “小脑”向基于强化学习和模仿学习的控制策略发展

传统机器人控制方法因高度依赖精确动力学模型及专家先验知识，在动态开放环境适应性方面存在局限。尽管数据驱动的学习型控制能通过经验优化策略，其泛化能力与环境鲁棒性仍待提升。大模型的引入为人形机器人“小脑”控制带来新突破，正推动控制范式从模型驱动向数据驱动迁移。

大模型通过整合先验知识显著提升数据利用率。如Language Plan利用GPT-3将任务描述解译为抽象行动序列，通过状态空间嵌入增强分层强化学习智能体的泛化性能。LOFT、T-EBM等模型实现语言指令到控制策略的端到端映射。在模仿学习方向，视觉-语言模型开辟新路径。CLIP-ASAP融合CLIP语义编码与因果语言建模，基于视觉观察与语言指令预测关键动作帧，支持复杂技能的长时程学习。当前挑战聚焦于实时计算效率、极端环境鲁棒性及决策可解释性三大维度，亟须突破多模块协同以实现真正的端到端自主系统。

（四）“肢体”构筑机器人的“钢铁之躯”

人形机器人的“肢体”是实现拟人功能的关键，涵盖芯片、传感器、执行机构（电机、灵巧手）等先进技术。这些技术协同工作，为机器人提供了类似人类的运动能力和交互功能，是其执行任务和适应环境的物质基础。

来源：中国信通院，《人形机器人产业发展研究报告》

来源：具身智能与人形机器人论坛.2025年6月7日.<https://event.baai.ac.cn/activities/898>

1.AI芯片：人形机器人的“心脏”

芯片是人形机器人智能的算力核心。在架构创新上，全球企业积极探索：存算一体架构打破“内存墙”，缓解数据传输瓶颈；神经拟态芯片模拟人脑神经元工作模式，实现低功耗动态处理；异构计算将CPU、GPU、ASIC优势整合，提升运算效率。制程与封装技术不断突破，台积电3nm工艺量产，让芯片性能显著提升；Chiplet技术在国际上广泛应用，通过芯片堆叠降低成本与设计难度。算法-硬件协同成趋势，Transformer架构推动专用加速器发展，如美国Groq推出的LPU，加速AI模型运算。

2.传感器：感知交互基础

多模态传感器融合赋予人形机器人感知能力。视觉领域，3D视觉传感器成焦点，特斯拉坚持纯视觉方案，而波士顿动力等企业通过激光雷达与深度相机结合，提升环境建模精度。触觉与力觉传感器方面，柔性触觉传感器应用突破，Optimus Gen2借此实现鸡蛋抓取；六维力传感器在国际上广泛应用，助力精准力控。多模态融合技术兴起，美国MIT研发的RoboFusion系统，通过视觉、触觉、力觉数据融合与强化学习，大幅提升工业装配精度。

3.电机：执行控制核心

电机作为人形机器人核心执行部件不断升级。在控制精度上，日本安川等企业的伺服电机，通过优化驱动器与编码器，实现纳米级定位与微秒级响应。无框直驱技术革新传动模式，瑞士Maxon等品牌产品能量转换效率超90%，减少机械损耗。轻量化与高功率密度成果显著，德国FAULHABER采用碳纤维材料和拓扑优化，使电机体积缩小20%~30%，功率密度达1.5kW/kg以上，契合人形机器人紧凑动力需求。

4.灵巧手：拟人化操作器

人形机器人灵巧手技术近年来发展迅猛，在自由度、感知能力与材料应用等方面取得显著突破。在自由度方面，灵巧手的自由度不断提高，特斯拉Optimus Gen 3灵巧手自由度增至22个，能精准复刻人类手部复杂动作；感知性能上，触觉传感器的应用让灵巧手可感知物体形状、硬度与纹理，实现对鸡蛋等易碎物品的精细抓取。同时，材料科学的进步促使灵巧手更轻量耐用，这些技术协同发展，极大提升了机器人执行精细操作与环境交互的能力，为人形机器人在多场景的应用拓展奠定了坚实基础。

三、全球人形机器人的典型实践与探索

近年来，人形机器人正以超出预期的速度渗透到人类生产与生活的核心场景中，这一进程的加速得益于两大关键驱动力：其一为人工智能、物联网等底层技术的跨越式突破；其二是硬件成本下降与算法效率提升所带来的规模化应用可行性。从技术视角看，深度学习框架的演进显著强化了多模态数据的实时处理能力，例如基于Transformer架构的模型使机器人能够同步解析视觉、语音与环境反馈信息，从而在动态场景中实现“感知-决策-行动”闭环的高效运行。从成本视角看，高精度传感器、仿生关节驱动器的微型化与成本下降，使人形机器人从“奢侈品”走向“平民化”，产品转化周期大幅缩短，具备规模场景应用的经济基础。

来源：产业前沿 | 2025人形机器人产业发展十大趋势。2025年6月13日。

https://mp.weixin.qq.com/s?__biz=MzUyMDc0MzI5Mw==&mid=2247522701&idx=1&sn=4b98371043e2271d25c45c715d0b354d&chksm=f87ce79d479e4ae68f30267be20c24e2332af3a0f6196c404d1c387d7dcf1bfd

（一）人形机器人率先重构工业制造人机协同范式

在工业领域，人形机器人通过深度融合感知、决策与执行能力，正逐步成为推动智能制造升级的核心力量。随着工业自动化和智能化的推进，企业对机器人在复杂环境下的适应能力和灵活性提出了更高要求。当前，机器人在工业领域的应用已形成“单点突破-产线协同-全厂智能”的递进模式，其发展将经历三个阶段：初期与人类共处同一生产环境，重点解决人机协同问题；中期实现更高效智能的人机协作，但仍附属于人类操作；远期能够独立完成任务，人类逐渐淡出生产一线，“无人工厂”成为现实。

1. 典型场景及成效

工业制造场景是率先落地的主要领域，有望成为新型工业化的关键核心，为工业制造业的智能化升级提供支持。目前，人形机器人已经在智能巡检、柔性制造、精密装配等方面取得了良好的应用效果。在智能巡检场景中，借助多机器人协同与分布式智能系统，机器人能够优化任务分配和路径规划，例如结合红外夜视功能进行设备间温湿度监测、人员入侵识别以及跑冒滴漏预警，同时支持多端远程管理，多台机器人协同覆盖工厂车间等区域。在制造装配场景中，汽车、电子产品其内部结构复杂，包含大量零部件，机器人通过高精度的机械臂和灵巧手，可以进行精准的抓取、放置、组装等操作，完成上下料、搬运、电路板焊接、屏幕安装、电池固定等任务。例如，富士康合作优必选联合开发人形机器人应用于精密电子组装产线，探索高精度拧螺丝、元件贴装等微操作场景。

来源：从“表演”到“工作”，人形机器人离“进厂打工”还有多久？ | 机器人商业新纪元。

2025年6月18日。 <https://news.qq.com/rain/a/20250618A08EX000>

2. 未来发展趋势

在技术方面，工业人形机器人将从单机作业到“机器人班组”进化，实现群里智能协同，支持“一脑多机”调度。在应用方面，虽然人形机器人在工业制造领域已经有了一些较为成熟的应用，但要大规模进入工业应用场景，还需要一定的适配时间，工业制造场景的可靠性要求以及企业对成本的管控是制约其规模应用的主要问题。人形机器人首先在工业巡检、上下料、拖拽料车、质检、搬运等结构化程度高且节奏较慢的场景落地，未来在工厂等实际环境中应用时，持续采集和利用真实场景数据来优化自身的智能和性能，通过“数据飞轮”效应逐步实现工业场景中对精度和柔性有一定要求的任务。

（二）人形机器人探索构建普惠、精准、有温度的医疗未来

人形机器人在医疗领域的应用探索正从实验室迅速走向临床实践，其核心价值在于结合人类形态的灵活性、人工智能决策能力以及多模态交互技术，从而解决医疗资源短缺问题，提升诊疗精准度和个性化服务水平。2023年以来，一些通用人形机器人也开始用于医疗场景的试验。例如，美国Sanctuary AI公司让其Phoenix人形机器人在医院环境中执行简单杂务（递送物品、房间消毒）；中国的优必选推出过面向医院导诊的机器人“云帆”，可以引导患者就诊、回答咨询。

1. 典型场景及成效

医疗场景对机器人的要求很高：既要绝对安全可靠，又需要温和友善地互动。在临床干预场景下，人形机器人在外科手术中起到辅助作用，实现技术精度的突破与极限协作。如MIT的NanoSurgeon X1系统，配备原子力显微镜探针和量子纠缠触觉传感器，可识别细胞膜刚度差异，用于早期肿瘤边界定位。

在护理陪伴场景下，人形机器人为患者提供全面的生活支持和情感陪伴。如社交辅助机器人通过互动提升自闭症儿童的社交能力；喂食机器人通过感知和自适应技术辅助患者完成进食、穿衣等任务，并为患者提供康复锻炼的实时反馈与鼓励。例如，达闼科技Cloud Ginger 2.0通过自然语言交互识别100+种情感状态，结合多巴胺分泌预测模型，动态调整光照、音乐与对话内容，降低抑郁症患者PHQ-9评分14.3分。

2. 未来发展趋势

未来人形机器人在医疗领域的价值不仅在于替代人力，更在于拓展人类能力的边界，实现细胞级诊疗，通过计算机视觉、新型磁控材料与微小型磁性物体影像追踪设备等研发，以及可视化微纳操作技术与磁控微纳游动机器人生物体内靶向给药技术的发展，纳米机器人可以完成细胞内的靶向治疗工作，实现血栓清除、药物递送、癌症治疗等作业，构建普惠、精准、有温度的医疗未来。

（三）人形机器人将重塑交通物流生产力范式

在物流运输领域，物流机器人具备较强的自主决策和学习能力，能够适应更复杂、多样化的任务，是有望降低流通成本、辅助构建高效、快捷、智能化物流体系的关键因素。当前机器人在物流领域的应用主要包括拣选机器人、叉取机器人、搬运机器人、料箱机器人等。人形机器人的赋能能够在仓储、装卸、搬运、分拣、包装、配送等环节提升工作效率和管理水平。例如，亚马逊近期在其仓库运营中，已经在测试由其投资的公司Agility Robotics开发的人形双足机器人Digit，综合全面完成主要包括卸载货车、搬运箱子、管理货架等任务，大幅提高了仓库作业的效率。

来源：万亿空间！引爆市场！具身智能在各领域的应用前景深度分析 2025。2024年12月10日。

<https://mp.weixin.qq.com/s/rUeh99v6WAa3pg7B8XJ6HA>

来源：智源机器人产业研究院。通用智能与具身机器人：发展趋势与应用前景。2025年3月13日。

https://mp.weixin.qq.com/s/l_iQZDFR7oVUIKvCFtBZdA

1. 典型场景及成效

在柔性分拣场景，传统的自动化技术在面对非结构化场景时具有一定的挑战，而人形机器人通过激光雷达、摄像头和SLAM技术构建动态地图，对环境感知、路线规划和运动导航能力将明显增强，可以更好地适应可变环境，识别多点目标，自主调整路径并能够及时避障，能够赋能物流领域分拣、搬运等工作。在无人运输场景，机器人实现从干线运输到末端配送的全链路无人化。通过24小时不间断作业提高物流配送效率，降低企业运营成本。

2. 未来发展趋势

人形机器人在物流运输领域的未来发展趋势正从技术探索走向规模化落地，其核心价值在于结合人类形态的灵活性与环境适应性，突破传统自动化设备的局限。人形机器人的终极价值在于重塑物流生产力范式——通过“类人化”突破环境限制，以“智能化”实现无缝协作，最终构建零改造、全适应、自进化的物流系统。

（四）人形机器人将重构家庭生活的效率与体验

在家庭服务领域，家庭服务机器人已经从最初的扫地机器人发展到如今能够进行地面清洁、物品搬运和基本家务的多功能机器人。例如，1X公司与OpenAI公司正在深度合作开发一款具身智能类人机器人 EVE，它能够实现对人类日常工作环境的认知与理解，在与环境交互过程中学习、纠错并收集数据，完成自主居家和办公帮手任务。人形机器人在家庭服务领域的应用正从概念探索走向实际落地，其核心价值在于结合类人形态的灵活性与情感交互能力，重构家庭生活的效率与体验。

来源：《物流技术与应用》2024年10期(点击查看掌上电子刊)，

1. 典型场景及成效

在**家务执行场景**，机器人展现出诸多功能。通过移动底座在大的空间范围内实现长距离操作，机器人同时模拟人类双手进行备菜、翻炒、出锅，洗衣、逗猫、浇花等操作。如挪威1X公司的Neo Gamma机器人可实现吸尘、擦窗、衣物归位等操作，通过弹性马达仿生手实现精细抓取。在**儿童陪伴场景**，人形机器人又有着不同的作用。通过游戏化学习，培养儿童逻辑思维，学习习惯养成等。在**适老与情感陪伴场景**，人形机器人可以起到健康监护、情感交互以及生活辅助的作用。例如养老院部署的“飞燕机器人”，可监测老人心率、血压异常，提供用药提醒和紧急呼叫，降低意外风险。

2. 未来发展趋势

未来，人形机器人能够拟人化感知、使用传统工具、在非确定环境下自主执行任务，实现全场景家庭助手，像汽车一样走进千家万户，成为每个家庭不可或缺的生活伙伴和帮手，如康复、家务类任务等。

一是技术突破驱动场景扩展，多模态大模型与持续学习技术的融合将提升机器人在复杂家庭环境中的适应能力，推动从清洁、搬运的单一任务向健康管理、教育陪伴的综合服务升级。**二是成本下降与规模化应用**，随着供应链成熟和量产技术突破，家庭机器人价格有望大幅降低，加速C端普及。**三是生态协同与跨界融合**，家庭服务机器人将进一步融入智能家居、医疗健康等生态，形成“硬件+服务+数据”的全链条价值网络。最终，家庭服务机器人将从“功能工具”蜕变为懂需求、有温度、能进化的生活伙伴，重塑“家”的定义。

四、探索人形机器人未来发展新路径

（一）筑牢硬件根基，推动人形机器人产业标准互通

在硬件层面，耐用性、电池能源效率以及与软件的深度集成需求是人形机器人现阶段发展的主要挑战。未来，全球在人形机器人硬件方面的发展不仅需要考虑关键技术的突破和成本效益，还需考虑硬件通用性和标准一致化等多方面因素。在发展过程中，具体操作层面主要包括如下：

一是推动构建统一的人形机器人硬件使用标准，数据集通用共享，增强硬件运营与维修的通用性和可靠性，搭建全球或区域协作网络。在人形机器人的发展进程中，面临着技术差异与标准碎片化的问题。在硬件构型方面，针对细分领域机器人建立相对统一的硬件标准，通过制定标准化的接口协议规范和模块化架构，降低硬件维护难度，延长设备使用寿命；构建模块化硬件参数基准，提升硬件之间的互操作性；统一操作系统的通信协议和人机交互规范，借助标准化框架降低跨平台协作成本，推动行业厂商数据集的通用共享，推动形成覆盖技术研发、生产制造、运维服务全流程的国际协作网络。

二是扶持上游零部件厂商，聚焦底层硬件技术攻关与泛化规模化应用。建立跨国合作机制，支持引导人形机器人上游零部件厂商泛化发展，先“生存活下来”，确保稳定可靠的部件交付能力，与人形机器人整机厂有效协同。在芯片领域，场景定义硬件能力，重点突破异构计算架构的能效比瓶颈，通过算法和硬件协同优化降低场景应用的端到端延迟；在传感器领域，重点关注柔性触觉、六维力控等细分应用，建立多模态感知数据融合的开放协议标准；在电机领域，发挥供应链整合优势，推动“功率密度+控制精度+成本控制”的有效三维融合。

（二）强化感知能力，促进人形机器人技术创新

当前，人形机器人行业在发展中面临核心技术攻关、数据资源整合与规模化应用落地等主要挑战。一方面，人形机器人系统的全模态感知能力仍需突破；另一方面，动态交互场景下的高质量数据采集成本高、仿真与真实数据差异显著，制约了模型泛化能力提升。此外，机器人操作系统碎片化进一步阻碍了规模化效应的形成。为此，未来可从技术协同、数据闭环与平台生态三大维度系统布局，具体路径包括：

一是构建产学研深度协同生态，突破人形机器人全模态感知与端云协同技术瓶颈。首先，提升全模态感知能力，攻关端到端大模型。当前人形机器人大模型在视觉、触觉、听觉、嗅觉的全模态技术储备仍显不足，尤其是在力反馈和触觉反馈存在显著短板，目前针对复杂感知的建模能力仍较弱，未来需重点攻关端到端大模型能力，通过多模态数据融合技术，构建统一的感知-决策-控制框架。引入神经符号系统以增强多模态信息的语义对齐能力，并利用自监督学习减少对高质量标注数据的依赖。其次，针对端侧算力限制问题，推动端侧智算平台建设，深化技术研究，解决端云协同中的通信延迟问题。受限于端侧算力瓶颈，短期内难以将机柜级算力压缩至终端设备。因此，“端云协同计算”成为必然选择，云端负责复杂模型训练与全局知识更新，端侧聚焦实时性要求高的感知与控制任务。

二是推动构建虚实融合数据训练场体系，推进人形机器人仿真与真实数据深度融合。数据是未来人形机器人能力突破的关键壁垒，在数据收集和训练中面临成本高、仿真数据和真实数据差异较大等挑战。针对这些瓶颈，

未来可通过三大路径突破：首先，推动构建虚实融合的国际联合训练场体系。结合数字孪生技术搭建软硬协同的虚拟训练场，产业各方协同，建设高质量多模态语料库，实现数据采集效率与场景覆盖率的双重提升。其次，通过行业联盟、跨界合作等方式，共同构建高质量、大规模的人形机器人数据集，推进完善多模态数据闭环。开源数据集降低研发成本，加速技术迭代，吸引更多开发者参与。最后，融合仿真数据与真实数据，在实际环境应用中采集利用数据优化智能和性能，形成“数据飞轮”效应。发挥仿真数据优势，把仿真数据融入训练中。推动机器人进入工厂等实际场景，通过机器人传感器在真实场景采集收集的与物理世界交互数据，训练迭代自身性能。

三是构建国际人形机器人通用开发与网联平台生态，突破操作系统碎片化与多机协同调度瓶颈。人形机器人操作系统平台的未来发展将围绕通用化、协同化与规模化展开。首先，鼓励龙头企业及科研机构建立人形机器人通用开放平台，建设技术开源社区。通过统一的中央控制系统实现多机器人协同调度，并融合大模型驱动任务规划与数据驱动端到端技能执行的双核机制，为不同品牌、形态的机器人提供标准化交互接口与开发框架。其次，推动电信运营商、互联网、云厂商等参与者构建人形机器人设备网联平台建设，释放人形机器人的规模化应用潜力。促进百种千型万机的人形机器人设备连接、管理与运维。

（三）聚焦重点场景，驱动人形机器人应用健康发展

人形机器人作为人工智能与实体世界深度融合的关键技术，不仅能够提升制造效率，还将重塑产业形态。

一是人形机器人行业应用方面可以走差异化发展路线，多形态多场景阶段性落地。在形态上，早期重点布局难度较低的轮式机器人，后期重点布局全人形机器人；在应用场景上，分类施策场景牵引，“小应用，大推广”。在重点行业和业务场景的选择上，遵循“循序渐进、由易到难”的原则。首先，在重点行业方面，从汽车制造业导入，逐渐渗透到半导体制造和医药等行业。制造业流程化的特点使得人形机器人技术落地应用方面占据先发优势。工业人形机器人能够有效提升工厂生产任务的灵活性与适应性。其次，在重点场景方面，前期规模化落地重点关注制造行业中的重点环节，在上下料、搬运、巡检等环节进行规模化应用。未来随着技术的成熟，针对不同流程环节，重要性不一样，提升制造速度。

二是构建国际人形机器人协同创新合作机制。通过定期组织技术研讨会与成果对接活动，推动在具身感知、人机交互、自主决策等核心技术领域的知识共享与标准协同，重点突破多模态数据融合、环境自适应等共性技术瓶颈。鼓励各国科研机构、高等院校、科技企业及政府部门加强合作，分享前沿研究成果与典型应用案例，共同推进全球范围内人形机器人技术研发与标准化进程。同时，推动设立国际人才交流专项计划，支持科研人员、工程师及学生在生成式人工智能等相关领域开展互访、联合培养与协同攻关，进一步促进技术创新要素的全球流动与深度融合。

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

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

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

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

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

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

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

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

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

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

services.

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

software integration. Future progress in this field will depend not only on technological breakthroughs At the hardware level, the primary challenges include durability, battery efficiency, and deep

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

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

"home."

understand needs, offer warmth, and possess the capacity to evolve, reshaping the very definition of Ultimately, household service robots will transform from "functional tools" into life partners that full-chain value network encompassing "hardware + services + data."

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



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

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

1. Typical Scenarios and Outcomes

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

2. Future Development Trends

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

Source: Logistics & Material Handling, Issue 10, 2024 (Click to View Mobile E-Journal).
Source: China Media Group | How Humanoid Robots Step into Real-World Application Scenarios, March 23, 2025.
<https://news.cctv.com/2025/03/23/ARTIX33ziNfTrV2GkS8epsQXr250323.shtml>

(III) Humanoid Robots Reshaping Productivity Paradigms in

Transportation and Logistics

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

1. Typical Scenarios and Outcomes

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

2. Future Development Trends

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

Source: Zhiyuan Robotics Industry Research Institute. General Intelligence and Embodied Robots: Development Trends and Application Prospects. March 13, 2025. <https://mp.weixin.qq.com/s/LiQZDFR7oVUIKvCFtBZDA>

Source: Trillion-Dollar Potential! Revolutionizing the Market! An In-Depth Analysis of Embodied AI's Application Prospects Across Industries – 2025 Edition. December 10, 2024. <https://mp.weixin.qq.com/s/rUeh99v6WAA3pg7B8XJ6HA>

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

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

1. Typical Scenarios and Outcomes

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

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

2. Future Development Trends

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

1. Typical Scenarios and Outcomes

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

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

2. Future Development Trends

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

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

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

III. Global Humanoid Robots: Typical Practices and Explorations

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

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

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

compact power sources in humanoid robots.

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

As the core actuating components of humanoid robots, motors are continuously being upgraded.

improve the accuracy of industrial assembly tasks.

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

The fusion of multimodal sensors endows humanoid robots with sophisticated perceptual

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

Chips serve as the computational core of a humanoid robot's intelligence. In terms of architectural

environment.

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

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



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

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

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

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

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

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

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

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

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

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

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

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

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



Figure 5 Overview of Foreign Company Financing
(Source: China Unicom Research Institute)

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

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

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

II. The Technological Evolution of Humanoid Robots

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

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

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

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

EU is actively advancing the development of embodied intelligence, with a focus on its safety and intelligence. Through research initiatives like Horizon 2020, these frameworks have supported collaborative research among European countries in the field of humanoid robotics.

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

2. Rapid Development of the Global Humanoid Robot Market

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

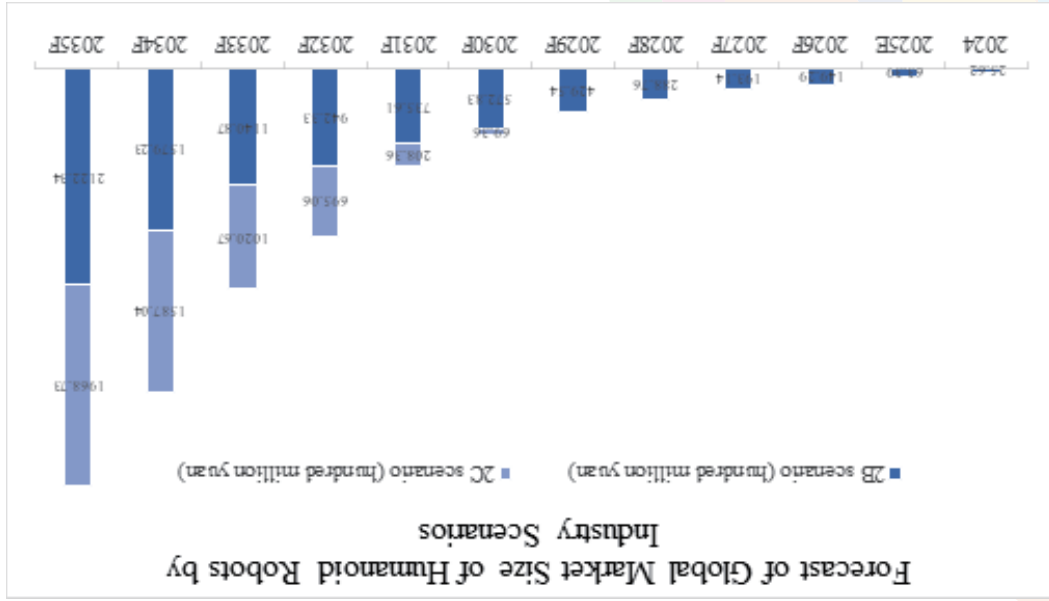


Figure 3 Global Market Size and Outlook of Humanoid Robots
(Source: Gaogong Robot Industry Research Institute)

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

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

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

(II) Broad Prospect in the Global Humanoid Robot Market

(Source: China Unicom Research Institute)

Figure 2 Development History and Outlook of Humanoid Robot



2. Development of Humanoid Robot

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

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

From 2000 to 2010, during the stage of interdisciplinary integration and technology accumulation, humanoid robot research began to incorporate methods and technologies from diverse fields, including mechanism science, machine learning, and robotics. This period essentially marked the emergence of humanoid robotics as a distinct disciplinary branch.

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

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

I. New Development Trend of Humanoid Robot

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

(1) The development status of humanoid robots

1. What Is Humanoid Robot

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

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

Members of the Writing Group

Chairs:

Li Hongwu, Director of the China Unicom Research Institute
Chen Hui, Dean of China Branch of BRICS Institute of Future Networks

Vice Chairs:

Yang Jinzhou, China Unicom Research Institute
Zhang Yang, China Unicom Research Institute

Members:

Guo Yaolong, China Unicom Research Institute
Yang Zheng, China Unicom Research Institute
Luo Lizhuo, China Unicom Research Institute
Xia Fan, China Unicom Research Institute
Xue Jing, China Unicom Research Institute
Han Yingying, China Unicom Research Institute
Lin Zhen, China Branch of BRICS Institute of Future Networks
Li Jichao, China Branch of BRICS Institute of Future Networks
Zhang Yawen, China Branch of BRICS Institute of Future Networks





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

Preamble



Table of Contents

I. New Development Trend of Humanoid Robot.....	1
(I) The development status of humanoid robots.....	1
(II) Broad Prospect in the Global Humanoid Robot Market.....	3
II. The Technological Evolution of Humanoid Robots.....	5
(I) Continuous Advancement in the Intelligent Perception and Decision-Making of Complete Robots.....	5
(II) Empowering the Robot's "Brain" with Multimodal Models and Algorithms.....	7
(III) "Cerebellum" Model Iteration and Optimization for Human-like Motion Control.....	7
(IV) The "Limbs": Components of the Robot's Physical Form.....	9
III. Global Humanoid Robots: Typical Practices and Explorations.....	10
(I) Humanoid Robots Pioneering the Reconstruction of Human-Machine Collaboration Paradigms in Industrial Manufacturing.....	10
(II) Humanoid Robots Exploring an Inclusive, Precise, and Caring Medical Future.....	12
(III) Humanoid Robots Reshaping Productivity Paradigms in Transportation and Logistics.....	13
(IV) Humanoid Robots Reconstructing Efficiency and Experience in Home Life.....	14
IV. Explore New Paths for the Future Development of Humanoid Robots.....	15
(I) Solidify the Hardware Foundation and Promote Interchangeable Standards in the Humanoid Robot Industry.....	15
(II) Enhance Perceptual Capabilities and Foster Integrated Innovation in Humanoid Robot Technology.....	16
(III) Focus on Key Scenarios and Drive the Sound Development of Humanoid Robot Applications.....	17



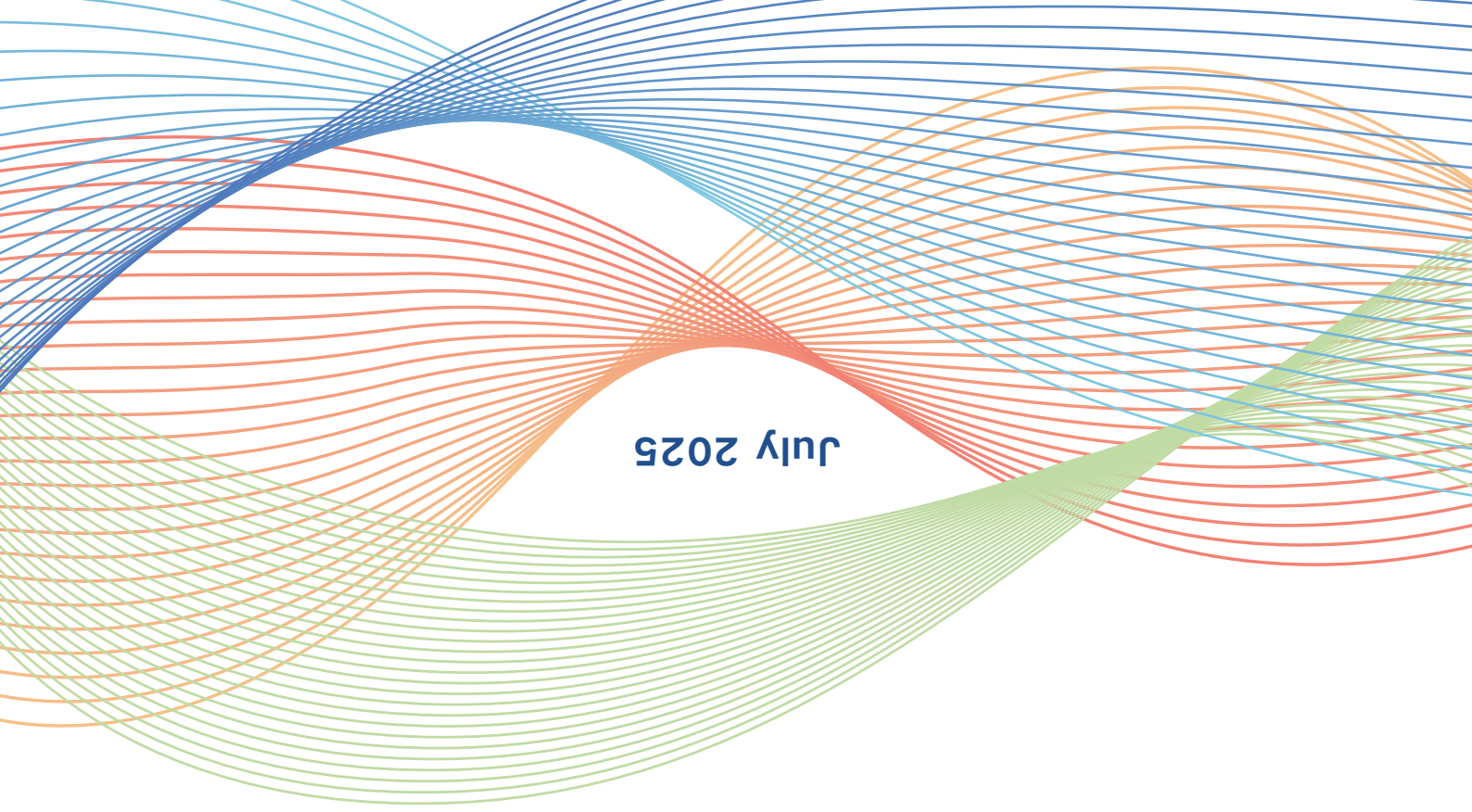
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Applications and Development Prospects of Humanoid Robots