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Transformation

Next Gen Tech: Robots

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Key takeaways

- What if generative AI (GenAI) could interact with the physical world? It could learn from a wider environment's worth of data and teach itself to do tasks that it was not pre-programmed to do, potentially changing the way we live and work in a countless ways.
- Enter robots: Robots use AI to interact with the physical world and learn from their interactions. They are equipped with a range of sensors and computer vision to take in data from the real world. Combined with GenAI, they can 'learn' from this data and exhibit conversational and situational awareness.
- But different robots serve different purposes. Here, we discuss the next generation of robots: humanoid robots, industrial robots and cobots, and autonomous vehicles, drones, and a myriad of other forms of embodied AI in action.
- Bank of America Institute's 'Next Gen Tech' series explores 30 breakthrough technologies across artificial intelligence (AI), computing, robots, communication, healthcare, energy and mobility, that are about to alter our lives. Join us as we discuss what's next on the tech horizon.

This publication is part of Bank of America Institute's 'Next Gen Tech' series – focused on sharing 30 breakthrough technologies that could transform the world. The series will highlight one of seven categories (artificial intelligence, computing, robots, communication, healthcare, energy and transport), and share advancements within each, so stay tuned for more.

Robots

In our series introduction, Next Gen Tech: Breakthroughs that will transform the world, Bank of America Institute discussed how rapid shifts in innovation are transforming businesses and the world. In fact, we noted that the fastest transformation in human history is ahead of us. First, we discussed innovations in AI, followed by computing, and here, we'll share the third of seven categories of breakthrough technologies – robots.

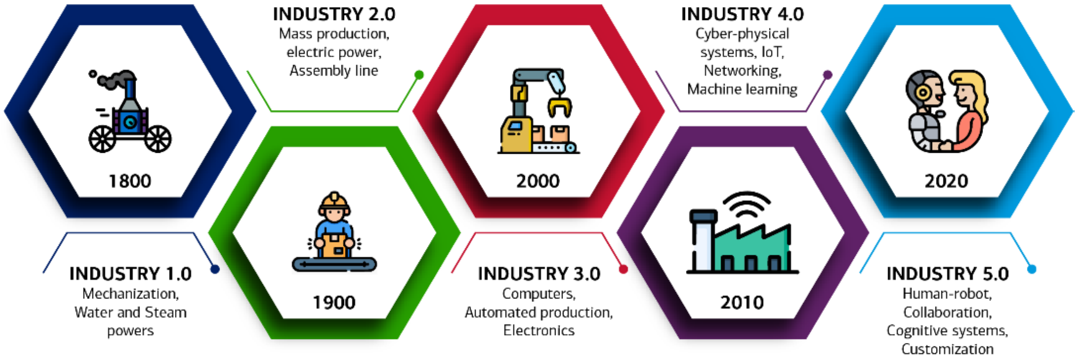
What if generative AI (GenAI) could interact with the physical world? It could learn from a wider environment's worth of data and teach itself to do tasks that it was not pre-programmed to do, potentially changing the way we live and work in a myriad of ways.

How can generative AI interact with the physical world?

The term 'embodied AI' was first used to describe the branch of AI that focuses on how computers, systems and technology can interact with the physical world. It typically includes AI for sensorimotor skills, navigation, and real-world interactions. But with the rise of GenAI, embodied AI is also being used to give this technology a physical form, typically a robot, including autonomous vehicles and drones.

Robots use AI to interact with the physical world and to learn from their interactions. They are equipped with a range of sensors and computer vision to take in data from the real world. Combined with GenAI, they can 'learn' from this data and exhibit conversational and situational awareness. For example, to teach a robot to pick up a book, the traditional AI method would be to program it with the movements that it needed (e.g., lower hand, open hand, close hand, raise hand etc.). In contrast, the embodied AI approach would be to teach the robot to guess by having it make random attempts and learn from each attempt until it achieves the goal.

Exhibit 1: The fifth industrial revolution involves the combination of humans and machines at work
Infographic illustrating the five waves of industrial revolution



Source: KnowHow

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New applications… towards autonomy?

Robots have the potential to enhance productivity and remove dangerous or repetitive or onerous tasks from humans. For example, they can help with assembly in warehouses (e.g., packing and shipping items). And though typically, we might think of robots as enabling us to automate tasks, with humans being the principal and robots being the agent, as these robots become more capable of self-learning and completing tasks without being pre-programmed, their direction may shift from one of automation to autonomy.

But different robots serve different purposes. Here, we discuss the next generation of robots: humanoid robots, industrial robots, and embodied AI in action, from autonomous vehicles to drones.

1) Humanoid Robots

Humanoid robots are a type of service robot that mimic human behavior and interaction. Service robots operate semi- or fully autonomously to perform services useful to the wellbeing of humans and equipment, excluding manufacturing operations.[1] They typically assist humans by performing jobs that are dirty, dull, distant, dangerous or repetitive, including household chores. Humanoid robots tend to be autonomous and/or operated by a built-in control system, with manual override options. And compared to other types of service robots, humanoid robots usually face more complex working environments, requiring sophisticated AI functionality to support sensing, motion control and interaction with humans.

2023 was a key year for humanoid robots

Last year marked the beginning of the rapid development of humanoid robots due to the breakthrough of large language models (LLMs). Companies have started combining GenAI and robots to create a new age of humanoid robots. Why? Because if GenAI systems have a physical form, they can take in even more information that can help them understand the world and human behavior. Embodiment can greatly expand capabilities and bridge the gap between natural language and robot control – a characteristic that could help GenAI reach artificial generative intelligence (AGI).[2]

How? (1) Putting GenAI into humanoid robots could help them identify human emotions and complete human tasks. AI would be able to analyze data on expressions (e.g., smiles, frowns, surprises, body language, tone of voice) that the human eye might miss; (2) making robots faster learners and deal with more complex tasks; and (3) helping robots understand natural language instructions better.

Humanoid robot supply chain

Humanoid robots are usually equipped with various types of sensors to measure key environment attributes such as position, orientation, speed, acceleration and contact force, and use cameras or LiDAR (light detection and ranging) for navigation. Inbuilt AI algorithms are responsible for path planning and behaviour control. Motion control is usually carried out by electric or electro-hydraulic actuators. A typical humanoid robot contains three major systems: (1) an actuation system, mainly including servo systems, controllers, and transmission machinery; (2) a sensory system, mainly including cameras and sensors; and (3) a computing system, including AI chips and relevant software for navigation and motion control. Other non-core components include batteries, screens, wiring, speakers, etc.

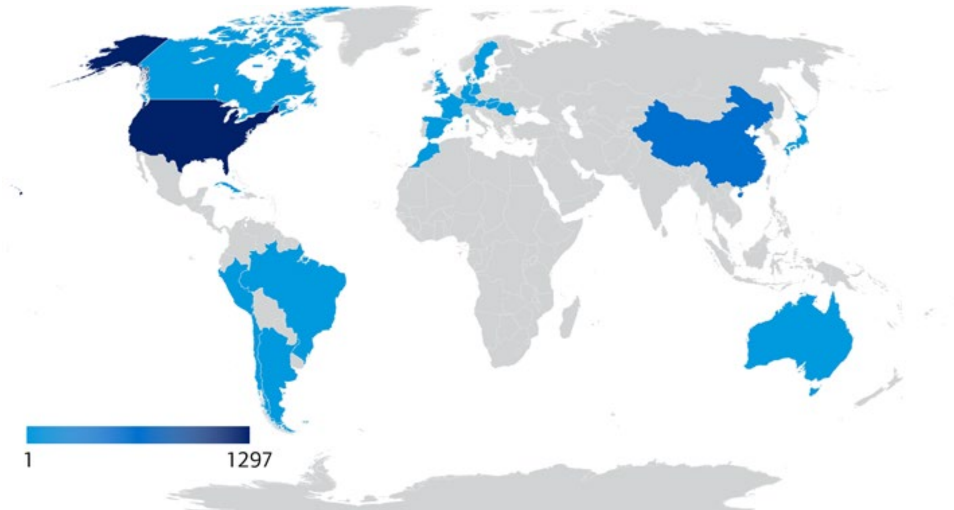
[1] IFR
[2] Australian National University

China's rapid development of humanoid robots

The US is the leading country in robotics adoption within the technology industry, with the highest number of robotics-related patents, jobs, and deals.[3] However, original equipment manufacturers (OEMs) in China have been rapidly developing their humanoid robots since 2022 and the breakthrough of LLMs, most notably the release of ChatGPT at the end of 2022, further accelerated the development.

Exhibit 2: The largest share of robotics-related patent filings in the technology industry in Q4 2023 was in the US with 34%, followed by China (24%) and Japan (5%)

Robotics-related patenting activity in terms of filings in the global technology industry



Source: GlobalData Patent Analytics. NOTE: Based on Q4 2023

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In early 2023, China's Ministry of Industry and Information Technology (MIIT) released their *Robot + Application Action Plan*, which highlights 10 sectors (manufacturing, agriculture, architecture, logistics, energy, healthcare, education, elderly services, community service, and emergency and extreme environment applications) that it would like to automate. The country aims to have c.500 robots per 10,000 workers by 2025.

Then, late last year, MIIT issued the *Guidance Opinion on the Development of Humanoid Robots*. By 2025, China aims to establish an initial humanoid robot innovative system and achieve technology breakthroughs in key components such as robots' brains, cerebellum, and limbs to ensure the components are supplied safely and efficiently. The humanoid robots are expected to be sold internationally and achieve mass production. By 2027, China intends to significantly improve the technological innovation capability of humanoid robots and form a safe and reliable supply chain system. From here, the industry could witness accelerating mass production with wider applications that are deeply integrated with the real economy, further stimulating economic growth.

What are the headwinds?

For one, the production cost of a humanoid robot is much higher than an industrial robot or a collaborative robot due to the large number of actuators and sensors. Secondly, a humanoid robot integrates large amounts of power-consuming components and due to the limited volume of the battery pack, the overall energy consumption needs to be controlled to ensure a reasonable battery life. Lastly, humanoid robots are required to work long hours in highly unstructured working environments, which calls for robustness. Robot developers need to address how to maintain desired motion/working ability amid unpredictable disturbances, which requires strong motion control and force-sensing capability.

There could also be public concern over the potential AI risks, which could affect the robots' uptake. And AI regulation could affect the evolution of embodied AI.

Into the real world…

- **Robotopia - Humans & robots, not humans vs. robots:** The collaboration between man and machine will be key to the future of work and jobs. The global robot installed base could double from 2019-25, hitting five million units. Yet, technological automation raises the need for coexistence between humans and industrial robots ('cobots'), one of the fastest growth areas. However, there is a scarcity of human talent with advanced skills due to a mismatch between

[3] GlobalData

technological advances (e.g., automation, AI, and machine learning) and the skills and experience that workers need to leverage these advanced tools.

- **Physical labor / warehouses:** Humanoid robots have higher levels of flexibility than typical service robots, usually with >20 degrees of freedom (refers to the motion capabilities of robots, typically the number of joints or axes of motion). They are generally able to perform various (usually unstructured) tasks. However, higher levels of flexibility translate into higher motion control requirements, and limits on height and weight.

- **People-facing roles / domestic applications:** Robots have typically been used exclusively for manufacturing, e.g., autos, but they can now work in warehouses, grocery stores, restaurants, hospitals, car parks, etc. This is because they can interact with people more naturally today, making them better suited to customer-facing roles. Other applications include security, warehouse management, household applications (e.g., housework, elderly care), point of information (e.g., hotels, airports), education (at school or home), healthcare/medical, and care home deployments for companionship.

- **Robonauts - Humanoid robots in space:** NASA's humanoid robot, Valkyrie, officially known as R5 (Robonaut 5), is being designed to operate in degraded or damaged human-engineered environments so that it might one day operate in space. Contrast this to the first two iterations, R1 and R2, which were used to perform repetitive tasks on the International Space Station. Valkyrie is being developed to mine resources, build habitats autonomously on Mars and work alongside astronauts. The robot has 44 degrees of body freedom, weighs 300 pounds, is 6 feet, 2 inches tall and runs on two Intel Core i7 chips.[4]

2) Industrial Robots

Industrial robots were first introduced in the 1960s and are a key enabler of the emerging Industrial Internet and Industry 4.0. They integrate robots, big data and software analytics to optimize the full manufacturing chain, connecting virtual design, simulation, manufacturing and supply chain management. This integration improves efficiencies and product quality, while increasing manufacturing flexibility and lowering turnaround time. In manufacturing, embodied AI can optimize production processes and logistics by deploying industrial robots with AI driven perception, navigation manipulation and decision-making capabilities.

Analogies with the human body

Equivalent to human intelligence, robots derive the information to operate through hardware controllers and software. Human arms and hands are represented by end effectors through which the robot ultimately performs its functions such as pick and place, welding and material handling. Actuators reflect human muscles, which set other parts like arms and end effectors in motion and transfer mechanisms act as robotic legs. Finally, sensors, like the human senses, receive feedback from the arm and end effector position and velocity, and transmit this information back to the controller.

The importance of machine vision

Both machine vision and computer vision are important divisions of AI. Machine vision is mainly applied in intelligent manufacturing, while computer vision is applied in many scenarios within the consumption sector. And with the advancement in machine vision systems, today's robots can be used in dynamic environments, operate with more flexibility, and adapt to changing environments.

Edge computing (See: Next Gen Tech: Computing) and deep learning models for AI are expanding what machine vision can do. When a computer receives a form of media (e.g., image or video), machine vision software can compare that image data with a neural network model. And the capabilities go beyond visual inspection and quality control. With smart machine vision, robots can use natural language processing (NLP) to read labels and interpret signs, understand shapes, calculate volumes, and optimally package objects – driving a shift from automating simple tasks to being autonomous machines.[5]

Structural driver: Demographics and manufacturing skills shortage

As the population is aging and fertility is decreasing, fewer workers are available, leading to a skills and labor shortage. According to a Korn Ferry study, the skilled labor crunch in manufacturing will cost the global economy $607.14 billion, with a deficit of 7.9 million workers by 2030. And the US specifically will suffer from a skilled manufacturing talent shortfall of 2.5 million workers in the next decade.

Industrial artificial intelligence

Industrial internet serves as the foundation for intelligent manufacturing. In the era of Industry 4.0, Intelligent manufacturing refers to the utilization of real-time data analysis, artificial intelligence (AI), and machine learning (ML), edge technologies, and cloud, in the manufacturing process to accomplish optimization in production, waste reduction, yield maximization, and cycle-time reduction. AI plays an important role in intelligent manufacturing as it enables business owners to monitor equipment and

[4] NASA
[5] Intel

processes correctly. General AI is widely used in various applications, as it processes high dimensional data such as picture, voice, and text. In contrast, Industrial AI processes low-dimensional data such as temperature, pressure, vibration, and more.

Digital twin

A digital twin is a dynamic software model of a physical thing or system that relies on sensor data to understand its state, respond to changes, improve operations, and add value. The concept of a digital twin has been around since 2000/2001 but with today's computing power, the development of the cloud, and the growing installed base of sensors, digital twins are now a reality.

In essence, the digital twin is a virtual representation of the behavior and structure of a physical product or process, providing numerous potential benefits, such as performance optimization, predictive maintenance, and reduced manufacturing downtime. It's important not to consider the digital twin as a single technology, but rather a combination: including a plant database, software (including artificial intelligence), sensors used to provide real-time feedback and much more. The concept is nothing new, however, the convergence of technological advancements in recent years, increases in computer power and number of connections, reduced data storage cost and capacity improvements, advancements in deep-learning modules and the advent of cloud data, have increased the efficacy and potential value of the simulated environment.

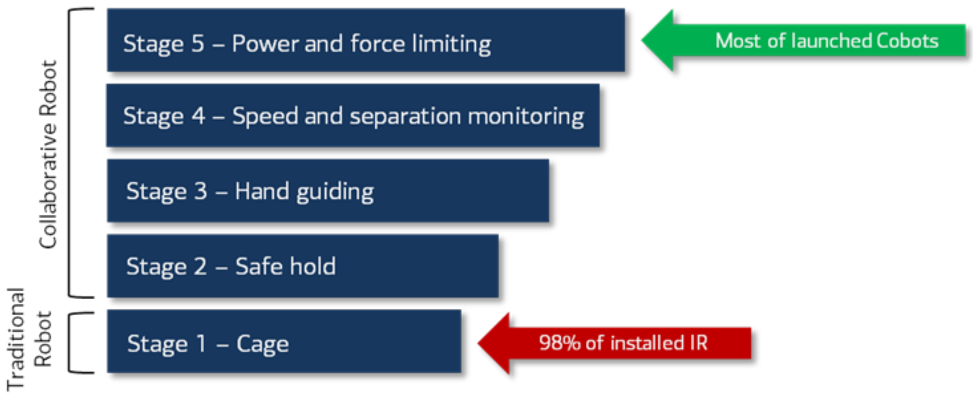
Rise of collaborative robots – "cobots"

Due to advancements in technology and motion-sensing capabilities, a new type of robot, known as collaborative industrial robots (or "cobots"), has emerged. These are small, nimble robots, specifically designed to move around a factory floor to assist human workers. Cobots are typically smaller, cheaper and easier to program than traditional industrial robots. The range of their capabilities has evolved over recent years, meaning the cobot is now a more competitive option for a customer looking to automate a factory without the need for large areas of fenced-off factory floor for their large industrial cousins.

Cobots are designed to conduct more complex tasks than traditional robots because they are powered by AI and machine. Technological advances, however, will make cobots more useful and are likely to spur manufacturer investment to invest due to rising labor costs and growth in edge computing. One of the fastest-growing areas of sensor development in automation and robotics is perception. Machine vision technology, laser scanners, structured-light 3D scanners, and the imaging and mapping software to support them are opening doors to robots in more industries.

Exhibit 3: There are four characteristics that a robot must exhibit to be defined as a cobot (safe hold, hand guiding, speed and separation monitoring, power and force limiting)

Most cobots on the market now have a full range of capabilities



Source: ARC Advisory Group Inc.

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Cobots also bring benefits to the factory floor in terms of optimized production, increased competitiveness, and an improved work environment where humans are freed up to focus on more rewarding tasks. This redeployment of human creativity interspersed with the robots' repeatability addresses market evolution and customer requirements for a high degree of product individualization.

And finally, in terms of warehouse automation, cobots are likely to be introduced for several reasons: (1) warehouses, even with a high degree of automation, often require human workers to engage in certain parts of operations that cannot be fully handled by robots. As such, robots that can work side by side with humans have an advantage; (2) cobots can be installed without securing space for safety fences, which reduces initial cost and is optimal for already-existing warehouses with limited space; and (3) cobots optimize the storage, distribution, and delivery of goods, while increasing the speed and accuracy of the operations.

3) Embodied AI

Other embodied AI interfaces include service robots, autonomous vehicles, agricultural robots, drones, spatial computing/virtual reality, and more.

- **Service robots** operate semi- or fully autonomously to perform services useful to the wellbeing of humans and equipment, excluding manufacturing operations. They typically assist humans by performing jobs that are dirty, dull, distant, dangerous or repetitive, including household chores. The rationale, use case and urgency for this technology may vary depending on the location and role, but some examples include preparing food, coffee, hospitality, entertainment, companionship, cocktails, home chores (such as vacuuming) or even looking after pets.

- **Autonomous vehicles (AV):** Self-driving is an AI problem – AV2.0 – where vehicles have the onboard intelligence to understand the surrounding environment and make decisions in real time, as opposed to the rules and mapping-based approaches that are adopted in most self-driving vehicle programs in operation. GenAI models can accelerate AV technology by providing vehicles with embodied intelligence to understand what's ahead and act on it. Furthermore, this "AV2.0" can be integrated into many new vehicles already in production without additional sensors/compute.

- **Agricultural Robots:** Within precision agriculture, autonomous robots can use AI and computer vision to differentiate between weeds and crops and, in learning from their environment, they can decide exactly when to spray weed killer, which can reduce the chemicals used in agriculture. (See: Feeding the future for more on this topic)

- **Drones**: Integrating generative AI into drones can allow them to process vast amounts of data and allow for autonomous navigation. This can also impact the future of transport, delivery and logistics and surveillance.

- **Virtual reality:** By blurring the lines between physical and virtual reality with more mixed and extended reality (XR) technologies, it opens up consumer, corporate and industrial applications, while also creating new media/advertising experiences. Embodied AI can create immersive experiences and avatars that can respond to human gestures and expressions and GenAI can make these virtual worlds seem more realistic, create digital avatars, and act as a tool to create intricate stories.

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Disclosures