SIEMENS

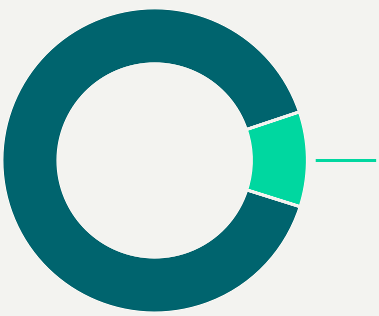
TECH TRENDS 2030: A SIEMENS FORESIGHT SERIES

The next era of **industrial robotics**

As a global technology leader, Siemens is committed to continuously scanning the horizon for emerging technology trends and translating these insights into actionable intelligence. This briefing marks the beginning of a series designed to showcase the key technological trends identified through Siemens' strategic foresight activities.

The field of industrial robotics is undergoing a transformative shift, driven by rapid technological advances and evolving market dynamics. Currently, the global landscape features approximately four million operational industrial robots, nearly double the number since 2016/17. Annual installations now surpass 500,000 units, predominantly driven by Asian markets – particularly China, which accounts for about 75% of these installations (International Federation of Robotics, 2023). This growth is largely due to strategic industrial policies, significant investments in automation to sustain competitive manufacturing sectors, and strong electronics and automotive industries.

Traditionally, industrial robots have been critical on production lines with well-defined, predictable tasks. They excel in high-precision applications such as assembly, welding, and painting. However, the landscape is rapidly evolving with the emergence of collaborative robots, or cobots, which now constitute about 10% of new installations and are growing much faster than traditional robots.



10%

Collaborative robots or cobots now account for 10% of new installations and are growing faster than traditional robots

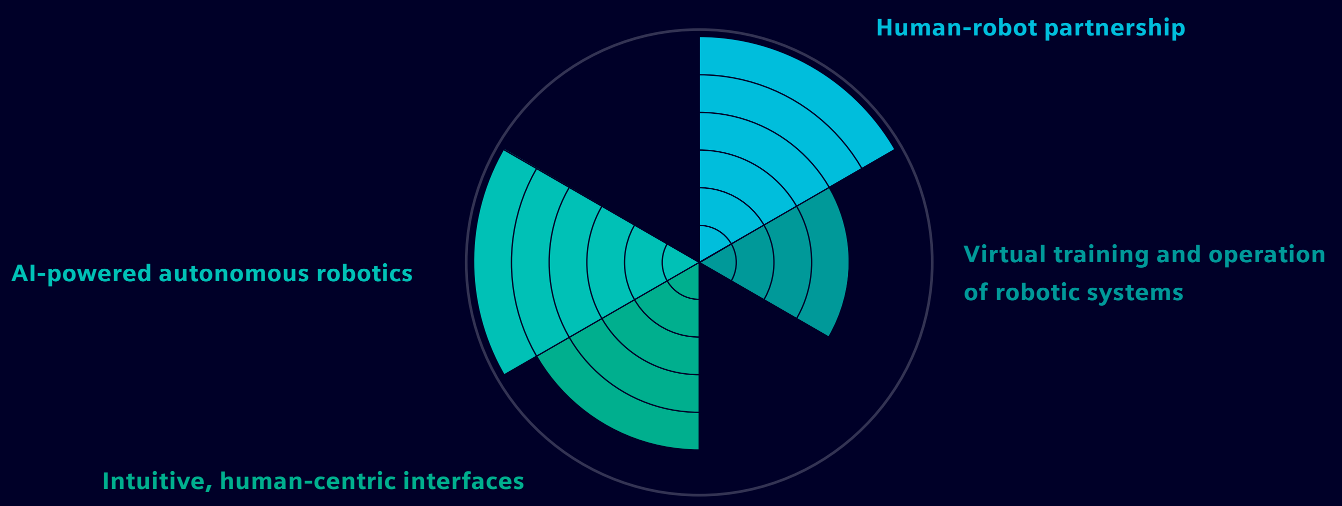
Despite the perception that cobots are meant to work directly alongside humans, actual collaboration is currently rare, as they are often not yet smart enough for true collaboration. However, cobots stand out for their ease of programming, compact size, lightweight design and low-energy consumption, making them suitable for mobile tasks and for environments with limited power access.

Furthermore, there is an increasing trend towards robots capable of executing more complex and less predictable tasks, as a direct results of advancements in artificial intelligence (AI). After all, robots are, in essence, "embodied AI" – physical manifestations of artificial intelligence – and their current abilities are directly constrained by the present limitations of AI. As AI continues to advance, particularly in areas like machine learning and perception, we can expect robots to become more autonomous, adaptable, and capable, leading to production lines that are more adaptable, with faster turn-around times and reduced overhead costs, thereby reshaping industrial competitiveness and economic landscapes.

Another result of AI-driven innovation is the emergence of humanoid general-purpose robots, with anticipation fueled by advancements in AI and recent eye-catching prototypes from US and Chinese startups. These robots are envisioned to operate independently without task-specific programming, potentially transforming sectors like assembly. While the full realization of this vision may be a decade away, we can expect significant progress in relevant subfields like assembly from these activities.

I. The evolution of industrial robots: **Key trends** on our radar

Currently, we see four main trends, driven by current advancements in technology and shifts in industrial demands, that will redefine the capabilities and roles of robots in manufacturing over the next six to seven years.



1. AI-powered autonomous robotics:
The rapid advancement of AI technologies, such as machine learning and machine vision, has the potential to revolutionize robotics. A prime example is Siemens' SIMATIC Robot Pick AI, a pre-trained deep learning vision software that simplifies piece picking for traditional robots, eliminating the need for task-specific software. AI-powered adaptability will also help cobots become more aware of their environments, making them increasingly competitive in many industries.

2. Human-robot partnership:
With advancements in smart mechatronic elements and motion control hardware and software, collaborative robots and exoskeletons can enhance human workers' physical capabilities and alleviate strain. Additionally, advanced AI and sensor technologies will enable robots to genuinely collaborate with and even learn from humans.

3. Intuitive, human-centric interfaces:
Advances in natural language processing and machine learning are transforming robot command execution, further enhancing collaboration. Inspired by large language models, future interfaces will feature intuitive, conversational inputs that simplify programming tasks. Generative AI innovations, like the Industrial Copilot, will enable engineers and floor workers to interact with robots through coding and natural language, making robotic systems more accessible and easier to integrate into daily operations.

4. Virtual training and operation of robotic systems:
Digital twins, advanced connectivity, virtualization, and software-defined automation can transform robotic training and operations. These technologies enable virtual simulations, allowing robots to be refined and trained digitally, which reduces costs and risks before real-world deployment. Software-defined automation ensures adaptability through dynamic updates. Remote operation from centralized, virtual control rooms improves global resource management and safety, particularly in hazardous environments. Looking ahead, the industrial metaverse offers the potential for even more immersive interaction with robotic systems, representing the ultimate convergence of these advancements.

These trends forecast a future where robotic systems are not only more autonomous but also seamlessly integrated within industrial operations. This evolution depends on the convergence of physical automation technologies like robotics with innovations like software-defined automation and industrial artificial intelligence. However, this convergence will manifest differently across industries and their specific processes depending on their current level of automation (see figure 1).

Industrial domains which are already highly automated today will see a further optimization and flexibility by, e.g., software-defined automation, while domains which still in the early stages – often due to the inflexibility of current systems or the limited tactile capabilities of today's robotics – are poised for a steeper evolution. Over time, this will likely lead to a situation where all industries converge on a similar level of advanced automation.

Converging automation: From optimization to transformation across industries

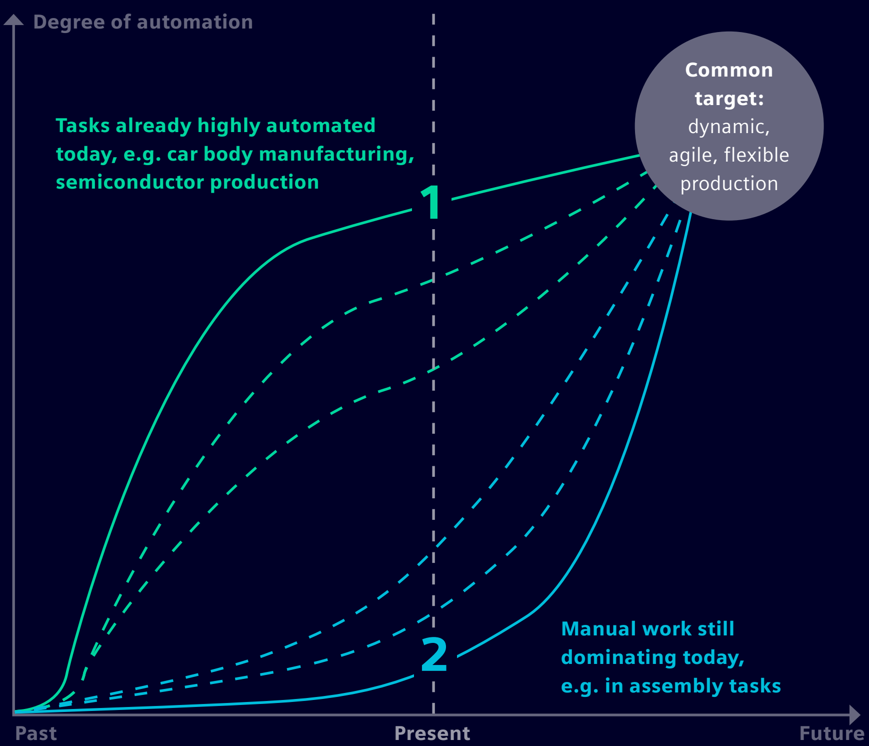
1 Advancing highly automated systems

- Seamless integration
- Utilization of digital twin and data
- Advanced connectivity, cloud and edge
- Software-defined control

2 Transforming less automated production

- AI-powered autonomy
- Modular automation
- Real-world perception
- Smart mechatronics

Converging pathways



II. The impact: Future scenarios

These developments and the emergence of advanced, autonomous robotic systems alongside compounding innovation in fields such as Extended Reality (XR), AI, and digital twins, will have far-reaching impacts. While predicting the exact future remains challenging – as always – several scenarios underscore the potential of these technologies to transform everything from daily operations on the shop floor to enabling agile and innovative business strategies and revolutionizing global supply chains.

Scenario I: Robot companions on the shop floor

Autonomous robotic systems will fundamentally change how we work in our factories. Imagine a factory floor where each worker is paired with a robot companion, specifically designed to complement their tasks. These robots, equipped with advanced AI, navigate the factory autonomously, delivering parts and tools just in time, without human intervention. This approach not only enhances efficiency but also helps mitigate the challenges posed by skilled worker shortages, allowing workers to focus on higher-value tasks.

As a worker assembles a complex machinery component, their robotic companion positions itself to supply the necessary items, utilizing machine vision to accurately identify and retrieve the correct tools and materials. In critical areas like welding or chemical processing, where precision and safety are crucial, robots handle the more dangerous tasks. They work in synch with human workers, who supervise and make critical decisions while the robots perform the operations.

Moreover, remote support through AR systems transforms the deployment of expertise in manufacturing. When robotic systems or human operators encounter issues they cannot resolve, experts can provide guidance for colleagues on site from anywhere in the world. Using AR technology, these experts can see exactly what the on-site personnel see, offering real-time instructions and support. This allows for effective collaboration and problem-solving as if the experts were physically present.

Scenario II: The automation of automation

Imagine future factories where advanced robotics autonomously manage production, constantly adapting through software-defined automation. These self-optimizing systems evolve in real-time without manual intervention. For instance, in the battery industry, robots could efficiently disassemble used batteries, making the process faster, easier, and safer for workers by handling hazardous materials. These robots could autonomously update their processes to adapt to new battery types, maximizing material recovery and improving sustainability.

The industrial metaverse provides a virtual environment where these processes are simulated and optimized before implementation, reducing risks and ensuring precise control. Experts can remotely manage and adjust operations, enhancing efficiency and enabling factories to quickly respond to changing demands. By automating these complex tasks, manufacturers can localize production, reducing reliance on distant supply chains and bringing operations closer to the markets they serve, ensuring faster delivery and greater responsiveness.

Scenario III: Cyber-physical management systems

At the strategic management level, advanced robotics act as the intelligent muscle, translating insights, ideas, and innovations from digital systems into real-world actions. Picture a scenario where a digital twin detects a flaw in the assembly line process. Instantly, the integrated management system updates the programming of robotic systems to correct the issue or adjust their actions, ensuring minimal disruption. This system can also autonomously adjust orders for materials if the digital twin predicts a shortage or shift production priorities based on real-time market data analysis.

The backbone of this technological interplay is the seamless integration of sensors, IoT, connectivity, cloud, and edge computing. This enhances how robotic systems interact with their digital and physical environments, ensuring that robots not only execute pre-defined tasks but also engage dynamically with real-time data and simulations. Moreover, the integration of software-defined automation platforms allows these robotic systems to be rapidly reconfigured and updated without extensive manual oversight.

Looking ahead, the industrial metaverse represents the ultimate convergence of these technologies. In this future scenario, real-time, immersive digital twins will enable even more comprehensive monitoring and optimization, pushing the boundaries of what's possible in agile manufacturing and strategic management.

Scenario IV: Localized and flexible manufacturing ecosystems

The integration of autonomous robotic systems and advanced communication networks is transforming global manufacturing by decentralizing production. Local factories now quickly turn digital designs into physical products. By sourcing materials locally and manufacturing on-demand, these factories minimize logistical overhead and environmental impact. This shift enables the production of products that are customized to local preferences and available almost immediately after ordering, drastically cutting the time from production to deliver.

The decentralization – or: glocalization – of production reduces dependency on complex global supply chains, lowers logistics costs, and decreases environmental impacts, enhancing supply chain resilience and aligning with global carbon reduction efforts. As production localizes, investment flows into diverse regions, fostering economic growth and technological innovation.

Furthermore, as robotics handle more complex manufacturing tasks, the global labor market is evolving towards higher-skilled job roles and continuous workforce upskilling. This transition underscores the need for comprehensive training programs supported by collaborations between governments, educational institutions, and industry leaders, preparing workers worldwide for the future of manufacturing.

III. Mastering the new era of industrial robotics: A holistic strategy

To excel in the new era of industrial robotics, businesses must adopt a holistic strategy that seamlessly integrates cutting-edge technologies from the shop floor to the cloud. This ensures that AI-powered robotic systems are integral parts of a connected infrastructure that includes edge computing, IoT, digital twins, and software-defined automation.

1. Seamless integration across digital platforms:

At the heart of this approach is the ability of robotic systems to interact in real-time with a network of digital twins and IoT sensors. This connectivity enables robots to turn digital insights into immediate actions on the shop floor, optimizing operations dynamically based on both real-time and predictive data. This also includes modern development environments to quickly engineer new automation solutions.

2. Leveraging edge and cloud computing:

By utilizing edge computing, robots can process data locally for quicker response times, while cloud computing offers expansive data analysis and storage capabilities. This dual approach allows for both speed and depth in data handling.

3. Software-defined automation:

Embracing software-defined automation allows robots to update their operations in real-time, adapting to new manufacturing processes or changes in production schedules without manual reprogramming.

4. Utilizing the Digital Twin:

Digital twins play a crucial role, providing a virtual representation of the physical world that robots can interact with to simulate and optimize processes before they are executed on the shop floor.

5. Strategic data utilization:

To fully capitalize on these technologies, businesses must also focus on leveraging the extensive data generated by robotic operations. Advanced analytics and machine learning algorithms analyze this data to optimize operational paths, predict maintenance needs, and improve efficiency.

6. Developing robust ecosystems:

Establishing robust ecosystems and partnerships is essential for continuous innovation. Collaborating with tech startups, academic institutions, and industry leaders can accelerate technological advancements and ensure that businesses stay at the forefront of industrial automation

7. Workforce transformation:

As robotics take on more advanced roles, developing comprehensive training programs and partnerships with educational institutions will be crucial for upskilling employees. This prepares the workforce not only to operate advanced robotic systems but also to engage in higher-level problem-solving and decision-making processes.

8. Regulatory and ethical compliance:

As robotic technologies advance, it is also vital to ensure they comply with emerging regulations and ethical standards. Developing and adhering to comprehensive ethical frameworks helps mitigate potential impacts on employment, privacy, and safety.

For more information, please contact our experts:

Dr. Georg von Wichert, Head of Research Group,
georg.wichert@siemens.com

Dr. Kai Wurm, Principal Key Expert Research Scientist,
kai.wurm@siemens.com

Dr. Stefan Jung, Principal Consultant,
Technology and Innovation Strategy,
s.jung@siemens.com

By integrating these technologies and practices, businesses can create a responsive, efficient, and adaptable manufacturing environment. This holistic approach not only enhances operational capabilities but also positions companies to thrive in a competitive, rapidly evolving industrial landscape.

Published by
Siemens AG

Siemens AG
Werner-von-Siemens-Str. 1
80333 Munich
Germany

www.siemens.com