Robots trends and megatrends: artificial intelligence and the society

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Abstract

Purpose – The purpose of this study is to analyze the robot trends of the next generation.

Design/methodology/approach – This paper is divided into two sections: the key modern technology on which Europe's robotics industry has built its foundation is described. Then, the next key megatrends were analyzed.

Findings – Artificial intelligence (AI) and robotics are technologies of major importance for the development of humanity. This time is mature for the evolution of industrial and service robots. The perception of robot use has changed from threading to aiding. The cost of mass production of technological devices is decreasing, while a rich set of enabling technologies is under development. Soft mechanisms, 5G and AI have enabled us to address a wide range of new problems. Ethics should guide human behavior in addressing this newly available powerful technology in the right direction.

Originality/value – The paper describes the impact of new technology, such as AI and soft robotics. The world of work must react quickly to these epochal changes to enjoy their full benefits.

Keywords Robots trends, Soft robotics, Artificial intelligence, AI and robotics, Robotics and workplaces, Education and robotics, Ageing workforce, Frugal innovation (FI), Climate change, Robot ethics, Control and systems engineering, Industrial and manufacturing engineering

Paper type Technical paper

Introduction

This study focuses on cutting-edge technologies that support innovative robotic breakthroughs and new industrial and commercial applications. The subject is vast and ambitious, with primary emphasis on Europe.

The interaction between science and society, in the background of culture, is a framework that provides inspiration and significance to human creative genius.

New technologies and applications have led to research trends and megatrends. Technologies are the foundation for advancing robotics development, while applications draw benefits to consumers and society (Figure 1).

Today, research and innovation are moving rapidly, allowing the accelerated development of robotic technologies and solutions. Society is undergoing fundamental changes, and the time to adjust to them is short. For example, distributed and compliant mechanisms may be adopted to create the next generation of medical and rescue devices (Van Roy *et al.*, 2020; Adel, 2022).

"Robots or workplaces" sounds like a Hamletic problem, but it is not. In 2025, half of the current jobs will be performed by robots, with a loss of 75 million jobs (From World Economic Forum, in collaboration with Forbes, 2020). In 2025, thanks to the automation and robotization of eliminated jobs, 133 million new, different and more qualified jobs will be created. Therefore, the positive balance will be 58 million new jobs for both women and men. Approximately two-thirds of the jobs transformed by automation will become more skilled, while the other third will be lower-skilled. Although the nature of these jobs is uncertain, the future workforce must be educated appropriately.

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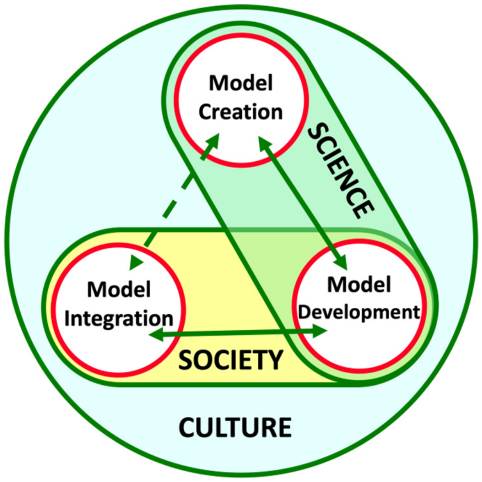
Figure 1 Link between science and society



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Technologies

This section summarizes some of the most important enabling technologies that will improve the capabilities of robotics today and in the future. Fast connectivity is made possible by 5 G technology, which also reduces the need for cables. Advanced robot control is enabled by artificial intelligence (AI). A real-time layer of safety and optimization was provided via a digital twin simulation for the system (Cepolina and Cepolina, 2021a, 2022b). Finally, compliant and soft mechanisms enable robots to interact more effectively with people and soft objects.

5G technology

The stability and data throughput of next-generation ultra-wideband networks are improved, while the latency is decreased. Compared to 4G, 5G latency is estimated to be 10 ms or less.

Without being bound by physical connections, robots can take advantage of the enormous computational power and storage offered by the cloud. With a speed of 1 Gbps, 5G reduces processing times for devices such as robots and self-driving cars (Lv *et al.*, 2023; Liu, 2021). New robotics applications, including computer vision and edge computing, are made possible using 5 G enabling technology.

Cloud computing is essential for the Internet of Things (IoT) because it helps preserve battery life, onboard power and computer resources. Robots will soon become capable of being accurately controlled from virtually anywhere in the world.

Robots can improve the 5G capabilities. Drones, which are famous for taking breathtaking aerial videos and checking structures, infrastructure and crops, have the potential to enhance mobile and Internet access for customers and emergency services. Poor mobile reception in rural locations can be annoying and dangerous during emergencies. Higher fatality rates are associated with delayed emergency response. Typically, base stations attached to structures or specialized masts transmit mobile signals. The "5 G Pan-European Trials Roadmap" proposes to attach a base station to a drone; the Finnish technology firm Nokia and British mobile operator EE have been flying small quadcopter drones, mounted with portable mobile base stations, in Scotland for the last two years. In case of an emergency, a drone can fly over a disaster area to provide instant mobile network coverage (Carr, 2021).

Artificial intelligence and robotics

Computer vision, expert systems, motion and manipulation and planning and scheduling are some of the main AI-cognitive technologies (Vrontis *et al.*, 2022). Some AI branches and tools have also been recalled (Table 1).

The cross-sectorial AI, data and robotics technology enablers represent the core technical competencies essential for the development of AI robotics systems (Figure 2). Sensing and perception create the information needed for successful decision-making, learning and interaction (Cepolina *et al.*, 2022a; Zhu *et al.*, 2022).

Knowledge and learning technologies cover the transformation, cleaning, storage, sharing, modelling, simulation, synthesizing and extraction of insights from all types of acquired data. Data are gathered mainly through sensing and perception. The consistency of data must be continuously evaluated.

Reasoning and decision-making are at the heart of AI (Fuchs, 2022; Géron, 2022). This technology addresses optimization, search, planning and diagnosis and relies on methods to ensure robustness and trustworthiness.

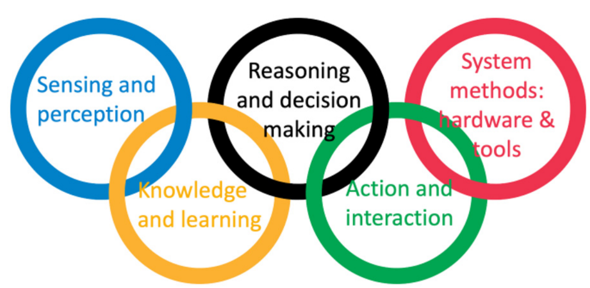
AI technologies need to interact smoothly and harmoniously to respect social, physical and environmental contexts. Actions and interactions occur between machines and objects, machines, people and machines and environments and machines. Interactions are shaped by real-time data acquisition, stored information, long-term knowledge accumulation and the use of multiple modalities and languages. Therefore, new modularity and interoperability standards must be defined. AI ensures the

Table 1 AI branches and tools

Branches of AI	Tools of AI
Knowledge & representation	Control theory
Machine learning	Deep learning
Perception	Logic and statistics
Planning	Neural network
Reasoning	Probability & uncertainty
	Search & optimization

Source: Authors' own work

Figure 2 Cross-sectional AI, data and robotics technology enablers



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robustness and transportability of the optimization, search, planning and diagnosis processes.

Today, it is possible to fuse AI techniques with control methods using advanced image processing. Autonomous navigation can also be achieved despite its limited accuracy and repeatability (Zorman *et al.*, 2022). Slow data processing is one of the main limitations of the AI.

The task was performed irrespective of the variations in the system and environment. The AI-based execution of tasks in real time in uncertain environments can be performed without *a priori* models. AI technologies are already used for image analysis (Van der Velden *et al.*, 2022), navigation to a target (Rezwan and Choi, 2022), grasping operations (Solowjow *et al.*, 2020; Molfino, 2014), pre-grasping, handling (Kim *et al.*, 2020), manipulation and release (Billard and Kragic, 2019).

AI-embedded robotics allows complex tasks with human interaction in an environment that is not fully known. Robots can serve in unstructured and poorly known environments, and are resilient to unknown events. Owing to image acquisition, objects can be identified and classified using object databases, computer vision and colored neural networks.

Navigation to a target is achieved by resorting to computer vision and autonomous navigation by fusing advanced robot control with learnable motion primitives (Shi *et al.*, 2019). Data inaccuracies are overcome through data redundancy.

The pre-grasping activity is performed by resorting to image acquisition and comparison with a database including object geometry, shape, picking locations and handling configuration through reinforced learning (Sutton and Barto, 2018).

Path tracking can be performed using a smart control system, including reasoning and decision-making modules.

Object grasping and manipulation rely on computer vision and reinforced learning (He *et al.*, 2019; de Souza *et al.*, 2022). Object release is based on *a priori* models and real-time information.

AI can serve well when robotic systems are extensively trained *a priori*; real-time situations must match the cases analyzed during the training phase. AI is not suitable for real-time applications, which are subject to changing task requirements and random interactions with humans and other mobile agents. AI is often unable to perform tasks with high accuracy, because probability, which is used to quantify uncertainties, denies accuracy.

Limited AI *a priori* training can be compensated by Repetition of Practicing, which provides training by execution. AI-based execution of tasks in real time in uncertain environments can be performed without a priori models and knowledge of real-time acquired data (Geron, 2022).

Artificial intelligence – cognition intuitive interfaces

Robotics and AI have great potential for assisting, augmenting and empowering humans. Aging populations and demographic changes will require new, innovative and sympathetic approaches to all aspects of human life.

AI helps in making more reliable and intuitive human–robot interfaces, which are inspired by the new functionality, with the enhancement of the performance of the human–robot environment physical interaction (Kumar *et al.*, 2021; Bicchi *et al.*, 2008).

The European research investigates reliable and intuitive human–robot interfaces, inspired by human motor functionalities; the development aims at the enhancement of performances of human-robot-environment physical interaction.

Different types of human-robot interfaces, such as robot receptionists, ask for and give directions through basic commands (Bazzano and Lamberti, 2018). Face expression, voice, in-the-air arm-pointing gestures, route tracing, hand clapping and touch are examples of intuitive communication.

AI control may be embedded in different embodiments, such as physical robots, virtual agents or interactive audio maps.

Smart sensors can enhance interactions among humans, robots and the environment. The AI's ability to learn from experience also makes robots close to humans.

AI supports multirobot system navigation and multiagent cooperation.

Digital twin

A digital twin is a dynamic digital representation of a physical system (twin) that is continually updated with the latter's performance, maintenance and health status data throughout the life cycle of the physical system.

Digital twin technology helps optimize operations by dynamically synchronizing the virtual and real worlds. IoT sensors instantly transmit assorted data from an object to its digital twin (Tao, 2022). As the conditions of the object change, the paired digital twin changes.

With the DT process, it is possible to create new customer and enterprise value through personalized services and drive product quality and advancements.

The twin allows us to know more about the behavior of the physical system. The user can apply new strategies to the digital twin. The digital counterpart remains updated during the life cycle by continually mirroring the physical system, quick and safe embedding and continuous improvement. Digital Twin can predict the breakdown and reinvent knowledge sharing in a machine environment.

A digital twin framework can support the design, construction and control of human–machine cooperation.

Soft robotics

Soft robots mimic the movement and adaptation of living organisms move and adapt to their surroundings. New soft devices can be made of soft and smart materials, compliant mechanisms, or deformable flexible links. Soft robots are flexible and adaptable (Liu *et al.*, 2023; Zhang *et al.*, 2023; Hartmann *et al.*, 2021). They can interact more easily and efficiently in real-world environments; therefore, they are also adopted in assembly lines. These robots offer improved safety while working with humans. This technology can be successfully applied to the medical (Cepolina and Razzoli, 2022c; Kyrarini *et al.*, 2021), rescue, food, agriculture and manufacturing sectors. Nonlinear modelling allows for the design of soft materials, while machine learning con improve the control (Kim, 2021).

Robotics megatrends

Owing to its low natality, the average population age is growing. The task of the new technology is to support an aging workforce. The availability of devices, that are easy to use and to program, brings automation closer to small and medium enterprises.

Robotics must rely on a solid security layer. Automation has been deeply changing after the pandemic digitalization and recent developments in AI.

Automation is becoming increasingly available in developing countries. People must accept the presence of robots in the workplace and at home.

Each year, IFR provides reports on the number of robots sold worldwide. In the professional service field, the number of robots sold for transportation and logistics applications (Zheng *et al.*, 2021; Arents and Greitans, 2022) is higher than that for agricultural applications (Figure 3). Hospitality (Rosete *et al.*, 2020) and medical and professional cleaning robots have similar sales. The sales trend for agricultural robots from 2020 to 2021 remains constant. In the same period (2021 to 2021), all the other robot applications recorded a sales increase: hospitality applications (+82%), transportation and logistics applications (+47%), professional cleaning (30%) and medical robots (+25%).

The innovation system

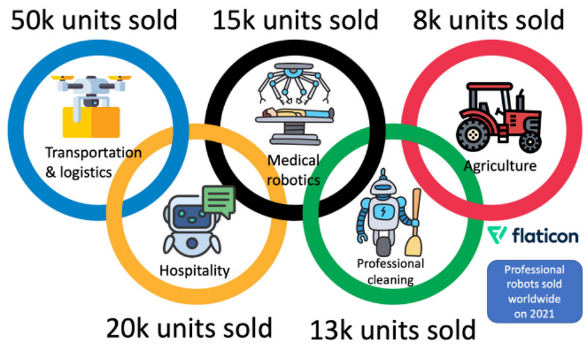
Dissemination is necessary to spread innovation through the market and nonmarket channels. The information goes from the initial implementation to different consumers, countries, regions, sectors, markets and firms. Without diffusion, innovation does not have an economic impact.

According to the firm's view, the geographical scope of the operating market can be domestic or international.

One of the main EU-applied research goals is to improve the efficiency of the technology transfer of project results to the industry from the last research call to new issues for the future. Edge technologies must be tested in real-world environments for both existing and future markets.

Technology push, customer needs and product costs must be harmonized. Research should provide breakthrough innovation to be embedded in the next industrial products (push). An economic impact is achieved if market consumers can immediately appreciate new innovative products at an acceptable cost (pull). Marketing matches customer needs with the technology offer. The sale price is based on customer expectations; margins are directly linked to the "sale of the dream" and to the technology cost. European industries have proposed a wide spectrum of new applications.

Figure 3 Professional service robots sold worldwide in 2021 (source IFR)



Source: Authors' own work

Industrial robotics perspectives

Standards need to be established as a common global language for robotics. Increased flexibility is required to quickly adapt to production and respond to changes in demand. The problem of standards is crucial, and all robotics associations and IFR are working on them (Figure 4). Thus, industrial robotics perspectives are promising.

Today, products have a short life and quickly become obsolescent. New products are made in small batches of increased quality, with a shortened time to market.

Resilience allows us to deal with production peaks and withstand systemic shocks such as COVID (O'Neill, 2021). Energy and resource efficiency improve the productivity and workplace quality of manufacturing employees. In addition, weak employees benefit from robotic aid.

Connected collaborative robots create unified manufacturing architecture (Ribeiro *et al.*, 2021; Knudsen and Kaivo-Oja, 2020).

Industrial robot challenges

Along the path of human development, enabling technology enables us to forge new devices to assist humans. New industrial robot challenges are born (Figure 5), and past goals contribute to our wealth. Across the industry, there is a race to offer the fastest and cheapest fulfilment delivery and services.

Figure 4 Robot associations

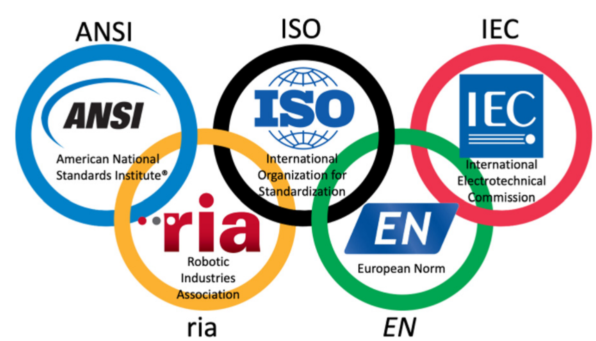


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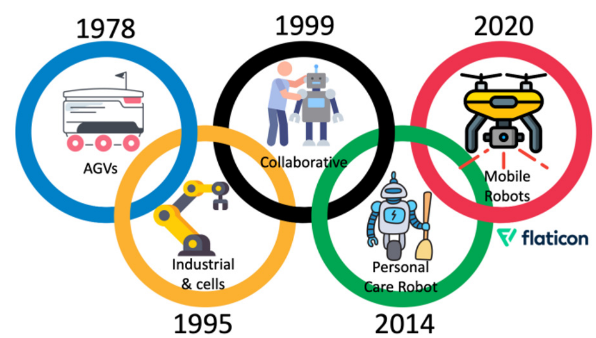
Figure 5 Industrial robot challenges



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However, automation is evolving faster than protocols and standards. Robots now have different sizes, capacities and onboard intelligences. Robots work in close contact with humans. Robot safety must be a top priority for all stakeholders.

The development of safe robotic solutions is encouraged in risky industries of transportation and warehousing because these fields are among the most dangerous.

Robotics and circular economy

The concept of a circular economy (CE) was first introduced by two British environmental economists, David W. Pearce and R. Kerry Turner (Pearce and Turner, 1989). In Economics of Natural Resources and the Environment, they pointed out that "a traditional open-ended economy was developed with no built-in tendency to recycle, which was reflected by treating the environment as a waste reservoir."

CE requires the industrialization of new operations to maintain, reuse, remanufacture and recycle products (Sarc, 2019). Recycling operations are difficult because of the extreme variability in the shape and status of the preservation of technology waste.

A multisensory system is needed to operate them correctly.

Thus, sophisticated cooperative hands are required. Recycling precious raw materials, such as rare earth elements and gold, is a common practice.

Education and vocational training

We must promote and realize the accelerated acquisition of new skills and develop and offer new scaled vocational education and training (VET) and higher education (HE) activities. Newly developed qualifications and guidelines need to be strongly focused on industry and societal needs.

Education and training must be harmonized and networked.

The time between the two generations of technology is much shorter than that for human life. For example, recently, we have assisted in the switch from paper to digital technology, and from analogic phones to smartphones. Citizens and workers must adapt positively to these technological challenges.

We must invest in continuous learning while creating social awareness about the importance, risks, and perspectives of new technologies. The school finishes at 17 years, and dissemination, information and updates should be lifelong.

Boosting skills and competencies is crucial and will become ever more important for automation, robotization and digitalization.

Social integration and worker mobility must also be supported. Society has the task of helping people find new jobs and reducing income inequality.

Disruptive innovations

Disruptive innovation significantly impacts the market. Innovation has a direct effect on people's daily lives These impacts can, for example, change the structure of the market, create new markets, or make existing products obsolete. However, it might not be apparent whether an innovation is disruptive until long after it has been introduced. One of the main concerns related to robotization is the long time required to metabolize innovation.

Skills, education and workforce of the future

Many workers work in sectors that have not yet been developed, and new jobs and workplaces are born daily.

Cooperation with Universities, industry, Research and Technological Development and professional training centers is useful for developing these skills. Generally, academic institutions are suspicious of new technologies. Teachers are not flexible and are updating their teaching topics and methodologies late. On the other hand, learners must acquire the skills required for new jobs. It is very important to involve industrial representatives in VET and HE activities, as they provide a concrete point of view on the competencies they need.

Accelerated acquisition of new skills must be promoted and realized. Workers must be reconverted quickly to new jobs.

Frugal innovation

FI or frugal engineering is the process of reducing the complexity and cost of a good and its production (Basu *et al.*, 2013; Weyrauch and Herstatt, 2017). This usually refers to reducing unnecessary features from a durable commodity, such as a car or phone, to sell in underdeveloped nations. FI may also be fueled by globalization and rising revenue in emerging nations. Such products must guarantee original performance while being less expensive. This is challenging. Cost-effective production can be achieved by additive manufacturing. The following ideas are changing the world:

- emotion leads to action;
- creativity overcomes scarcity;
- be hearth powered;
- seek opportunity in adversity; and
- do more with less.

FI is a rapidly growing field of research that is likely to attract more attention. FL can create new market segments linked to new needs. It establishes inclusive innovation that is beneficial for resource-constrained economies.

Robot in the field of climate change

New technologies, including robotics, IoT, flexible automation, AI, virtual reality and augmented reality, offer sustainable solutions for measuring the impact of climate change, realizing new circular concepts of production and consumption. Environmental robots can overcome some of the limitations of traditional monitoring methods (Bogue, 2023).

These devices operate on all media and frequently provide datasets with enhanced spatial and temporal coverage. Robots can detect pollution and assist in identifying illicit activities that threaten the environment.

Risky tasks can be accomplished without human intervention. We know more about our world's status and direction; full acknowledgment of climate change allows us to create mitigation plans.

Drones can map and monitor air pollution and glacier melting. Marine robots monitor the state of the water. Robotic systems equipped with underground probes improve earthquake prediction.

On July 1, 2021, the ISR press introduced the problem of reducing the carbon footprint and how to address this problem using robots.

A full risk assessment was embedded in the design phase.

Robot ethics

Ethics are of paramount importance when assessing advanced AI robotics. Corporate social responsibility (CSR) and social risk are dynamic concepts (time/location) that depend on business development that differs from country to country (tax rules influence). CSR is a multidimensional process that includes social, environmental, ethical consumer, and human rights concerns regarding its impact on society. Responsible companies must integrate CSR into their core strategies and all their operations in close cooperation with all stakeholders.

Europe recognizes that in addition to science, technology, engineering and mathematics, social science and humanities (SSH) play a key role in analyzing and influencing robot design choices and operation behaviors with a direct societal impact. The involvement of sociologists and SSH representatives must be considered to better understand society's evolution and needs.

Following an interdisciplinary approach, new tools and forms of design must be adopted that consider the risks to people and society of possible malfunctions early, before they are realized through simulation, virtual reality, and digital twins. Smart infrastructures are equipped with sensors, and sensible data collection is the basis for understanding the occurrence of climatic environmental disasters in advance.

In 2015, the United Nations wrote the objectives for sustainable development (Figure 6), which must be reached by 2030. Robotics can contribute to preserving the Earth's resources. Clean water, affordable and clean energy, sustainable cities and climate action are needed. AI and robotics are crucial to the future development of humanity. However, some fundamental questions have arisen: What should we do with the robots? What should we do with robots? What can robots do for us? What risks do we have in the long term? AI also challenges the human view of humanity as the main intelligent and dominant species on Earth. This is one of the reasons why ethical issues are considered by all people worldwide. Smart logistics can help improve the sustainability of cities (Cepolina *et al.*, 2021b).

There is a broad consensus that accountability, liability and rule of law are basic requirements in the face of new technologies (European Group on Ethics in Science and New Technologies, 2018), but the issue is how they can be allocated responsibility (Lee, 2016). Should robots have the status of legal entities and persons?

Figure 6 United Nations transforming our world

Note: The 2030 Agenda for sustainable development (2015)
Source: United Nations Sustainable Development Goals

Concluding comments

The paper offers a small window on the future robotics trends. Different fields, such as AI and soft robotics, are briefly introduced and analyzed.

The social and financial impacts of technology described help understand better the society of the future. The world of work must react quickly to these epochal changes to enjoy their full benefits. The ultimate objective is to funnel this enabling technology to reshape robotics for a sustainable development.

EC countries must remain competitive to preserve their high quality of life. They must preserve their leading position in digitalization while safeguarding the culture built over millennia.

They must preserve their leading positions in digitalization and innovation. Europe must remain "smart, sustainable and inclusive" in the future: open to the world, mastering digital transformation and arising cohesion among the State members.

Advanced robots will leave laboratories to help us in our daily lives.

AI-enabled robots will take care of elderly people, allowing them to live in their homes and reducing the need to go to health centers. AI robots can also improve safety in hazardous environments and safeguard human lives. Owing to new enabling technologies, medical treatments will be optimized to improve the quality of life.

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