Robots in Industry

The Past, Present, and Future of a Growing Collaboration With Humans

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Robots have been part of automation systems for a very long time, and in public perception, they are often synonymous with automation and industrial revolution per se. Fueled by Industry 4.0 and Internet of Things (IoT) concepts as well as by new software technologies, the field of robotics in industry is currently undergoing a revolution on its own. This article gives an overview of the evolution of robotics from its beginnings to recent trends like collaborative robotics, autonomous robots, and human–robot interaction. Particular attention is devoted to the deep changes of the last decades, from the traditional industrial scenario based on isolated robotic cells up to the most recent coworking and collaborative robots. The role of robotics in the Industry 4.0 framework is analyzed, and the relationships with industrial communications and software technologies are also discussed. Some future directions for robotics are envisaged, focusing on the contributions coming from new materials, sensors, actuators, and technologies. Open issues are highlighted as well as the main barriers that currently limit the deployment of industrial robots in the small and medium enterprise (SME) world.

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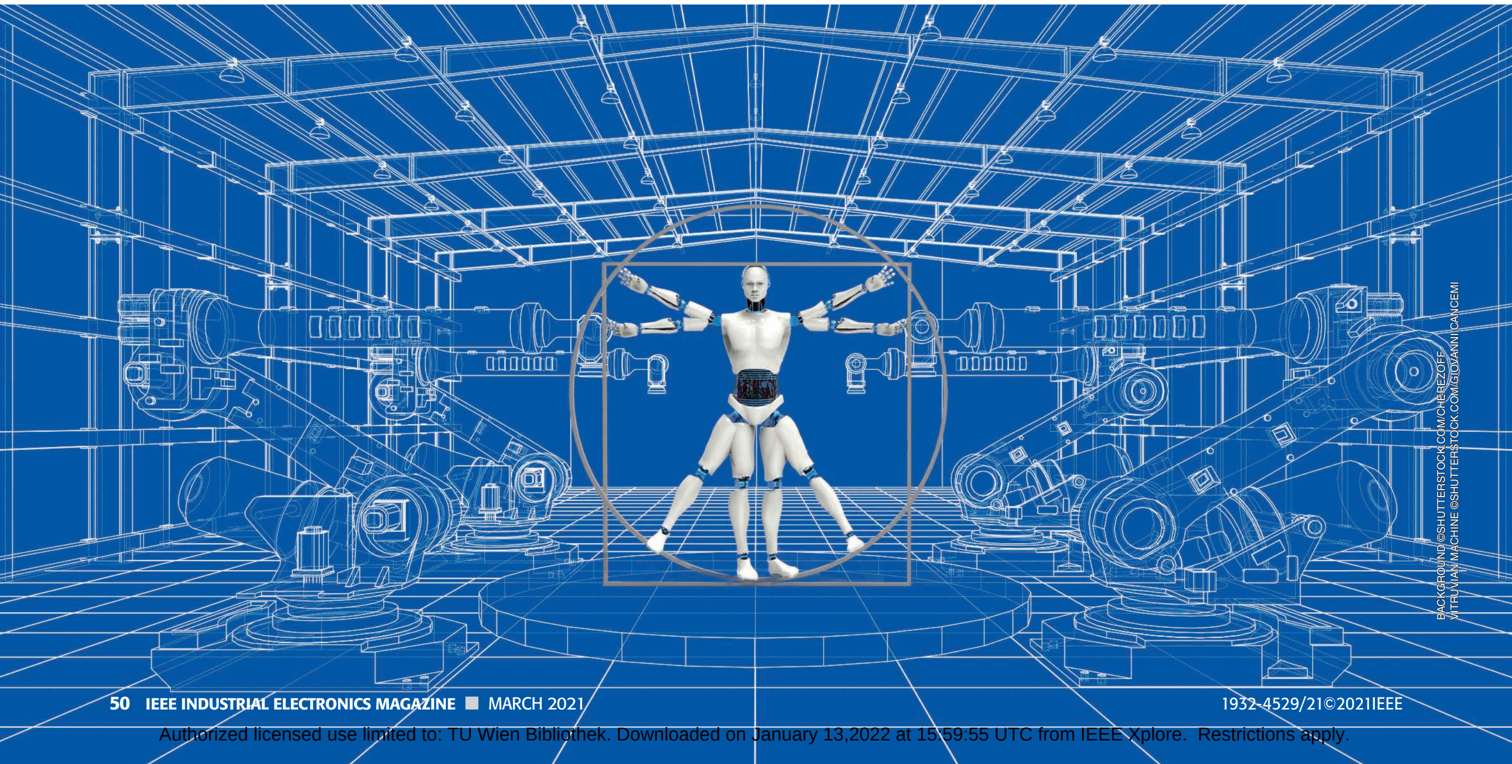
Background and Motivation

Throughout history, humankind has been fascinated by machines and devices able to imitate the functions and movements of living beings. The ancient Greek civilization had the word *autómatos* to refer to such devices. The first automaton was arguably built by Hero of Alexandria (85 AD), who made animated mechanisms that moved with hydraulic devices, pulleys, and levers, mostly for ludic purposes. For many centuries, various inventors created automatons, from Leonardo da Vinci to the loom of Jacquard (in 1801), Albert the Great (1204–1282), and Roger Bacon (1214–1294), to mention just a few. The automaton can be considered the forerunner of modern industrial robots.

The word "robot" was used for the first time in 1921 when the Czech writer Karel Capek (1890–1938) released in Prague his work, *Rossum's Universal Robot (R.U.R.)*, depicting class fighting in a society with automated workers. From that moment on, the term "robot" has been used by science fiction writers, and in 1926, the movie *Metropolis* finally made it popular around the world. Isaac Asimov first used the term "robotics" in science fiction books that inspired scientists and engineers to develop early industrial robots. He was the leading promoter of the word "robot."

In industrial practice, the fascination with human-like machines plays no significant role. Rather, robots have always been an element of automation, their main tasks being to relieve human



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workers from heavy, dangerous, or monotonous work and to improve product quality by increasing the precision and repeatability of manufacturing processes. A highly controversial aspect of the use of robots is the possibility to establish fully automated production lines, leading to almost personnel-free factories and serious threats to the job market, especially in the low-qualification segment.

While robots traditionally have been operated as stand-alone machines in confined production cells, there is a recent trend toward collaborative robotics and human–robot interaction [1]. This trend is closely connected to the Industry 4.0 idea and, more generally, to the concepts of the IoT and cooperating objects. It is fueled by recent developments from the IT world and industrial electronics or even material science. Crucial enabling technologies for these trends are, e.g., smart sensors [2] for a better perception of a robot's environment; industrial communications [3] for improved real-time interaction and coordination not only among robots but also with their surroundings; and the entire range of cloud and edge computing, permitting information acquisition and processing from the individual device up to the enterprise level (Figure 1). In this context, wireless communications play an eminent role as they support the mobility of robots as well as the inclusion of sensors or actuators around the actual robot [4].

The purpose of this article is to give a historical overview of the evolution of industrial robotics from its early stage to current developments and future trends. It will also shed some light on the communication and software technologies required for modern collaborative robotics.

A Taxonomy of Industrial Robots

Starting from the progenitors of robots, i.e., telemanipulators, Figure 2 provides a timeline of the evolution of industrial robotics together with some famous robots and the relevant milestones of technologies and sciences strictly related to robotics. The main achievements and communication standards relevant to industrial robotics are displayed separately. The figure also includes the publication timeline of some iconic movies on robotics. These movies are science fiction art, but they coined public perception of robotics over the decades.

The present and short-term evolution of industrial robotics can be seen in Figure 3. The installation of industrial robots is growing, with a high increment foreseen in 2020 and in the next two years. The largest growth is expected in Asia (10.9%), followed by America (8.4%) and Europe (6.3%). China continues to lead the installation of industrial robots, thus contributing to the big increase in Asia, together with Japan and South Korea. The increasing market in car manufacturing and electronics promoted the largest growth in the past year in robot installations in Asia, together with the still-emerging production in China. Figure 3(d) also reports the robot density ranking, i.e., the number of deployed industrial robots per worker in various countries.

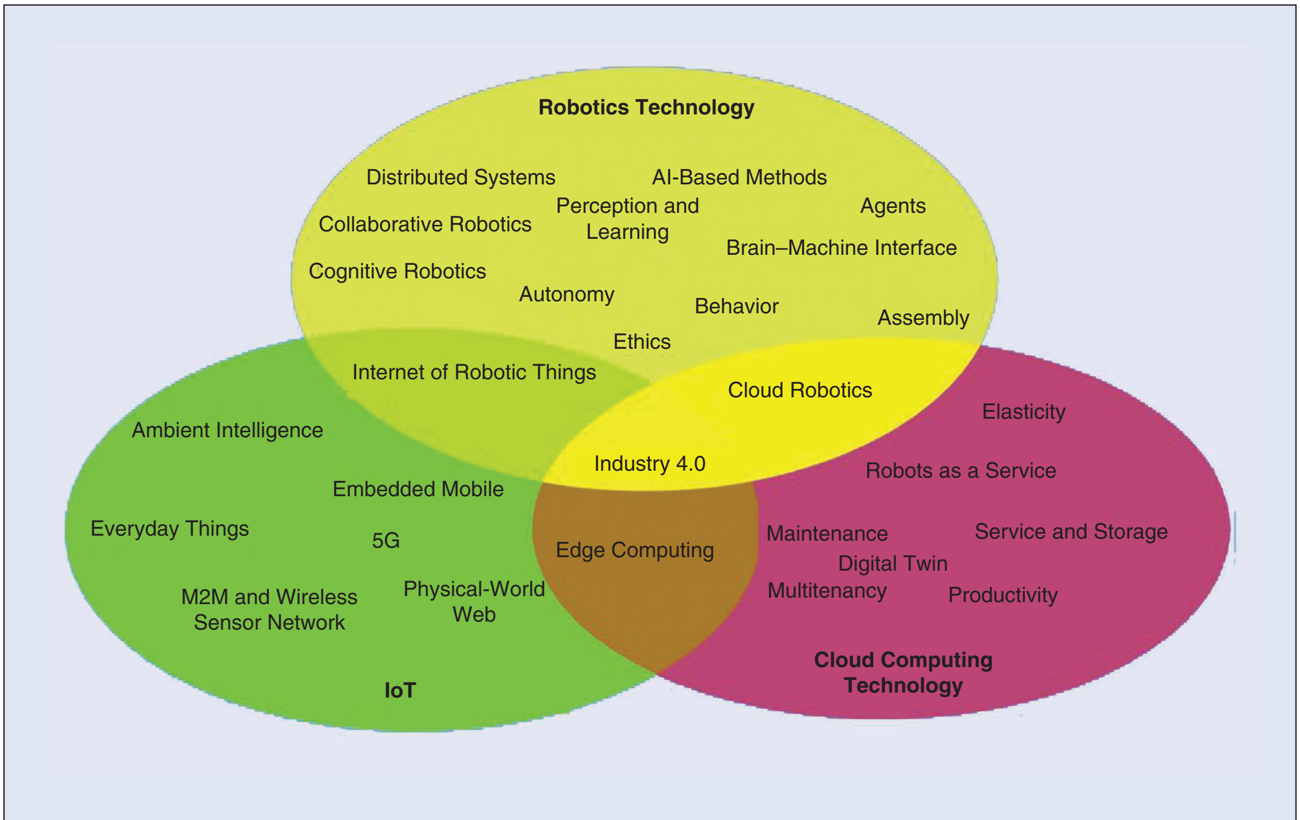

FIGURE 1 – The technology fields influencing modern robotics. AI: artificial intelligence; M2M: machine to machine.

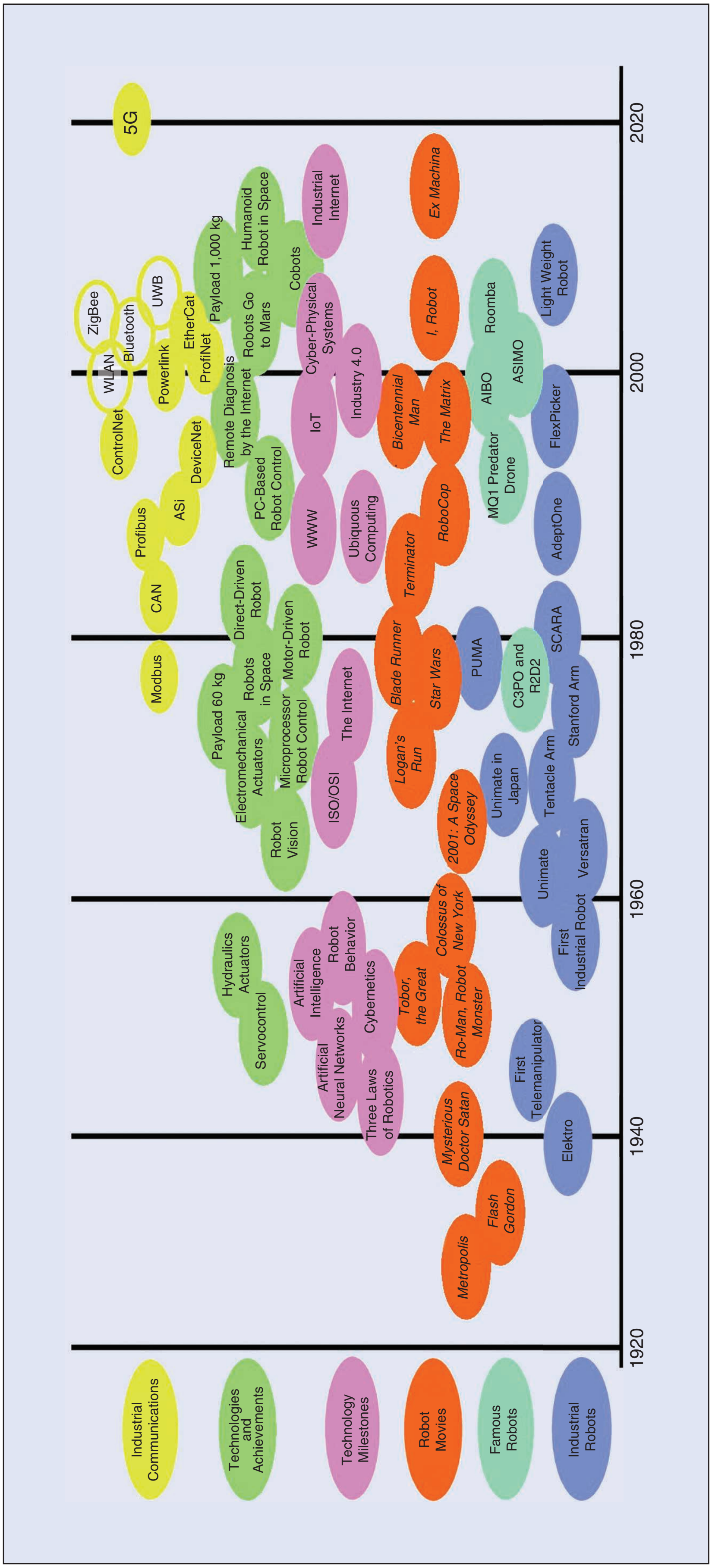

FIGURE 2 – A timeline of some remarkable aspects in robotics.

Globally, the automotive industry leads the number of units installed in car and car supplies factories with an attractive 2% increment compared to the previous year, while the also-leading electrical/electronics industry shows a decrease of 14%. Worth noting is the increase of 32% of units in the food industry, which includes beverages and tobacco production. Other industries that have a large growth are mainly relevant to agriculture, mining, construction, and education and are included under the "All others" label in Figure 3(c). As with the general industry, the robot industry devoted to robot production foresees a huge increment for the next years.

Today, robots are extensively used in industry, being an essential element in most manufacturing processes. Table 1 displays the most typical robot operations in the industrial field, with some highlights. New application fields are currently opening, for example, agriculture, construction, domestic and hazardous environments, medicine, and health.

From Isolated to Coworking Robots

In the 1990s, industrial robots were already advanced mechatronic systems, synergistically integrating mechanical design, electronics, software, and control, but with no real awareness of what was happening around them. They mainly operated in an isolated way. There were automated production lines where robots seemed to work together, but this was not quite true. Each robot was actually an isolated manufacturing cell with a specific manufacturing task, whereas the cells were connected to the rest of the process by conveyor systems for workpiece handling. Even in cases where several robot arms worked together on one workpiece (like in car assembly lines), those robots were not programmed independently but as one machine with predefined movements. The lack of awareness, and hence the inability of those robots to vary their behavior in an autonomous way, implied strong constraints to guarantee safety. Consequently, classical

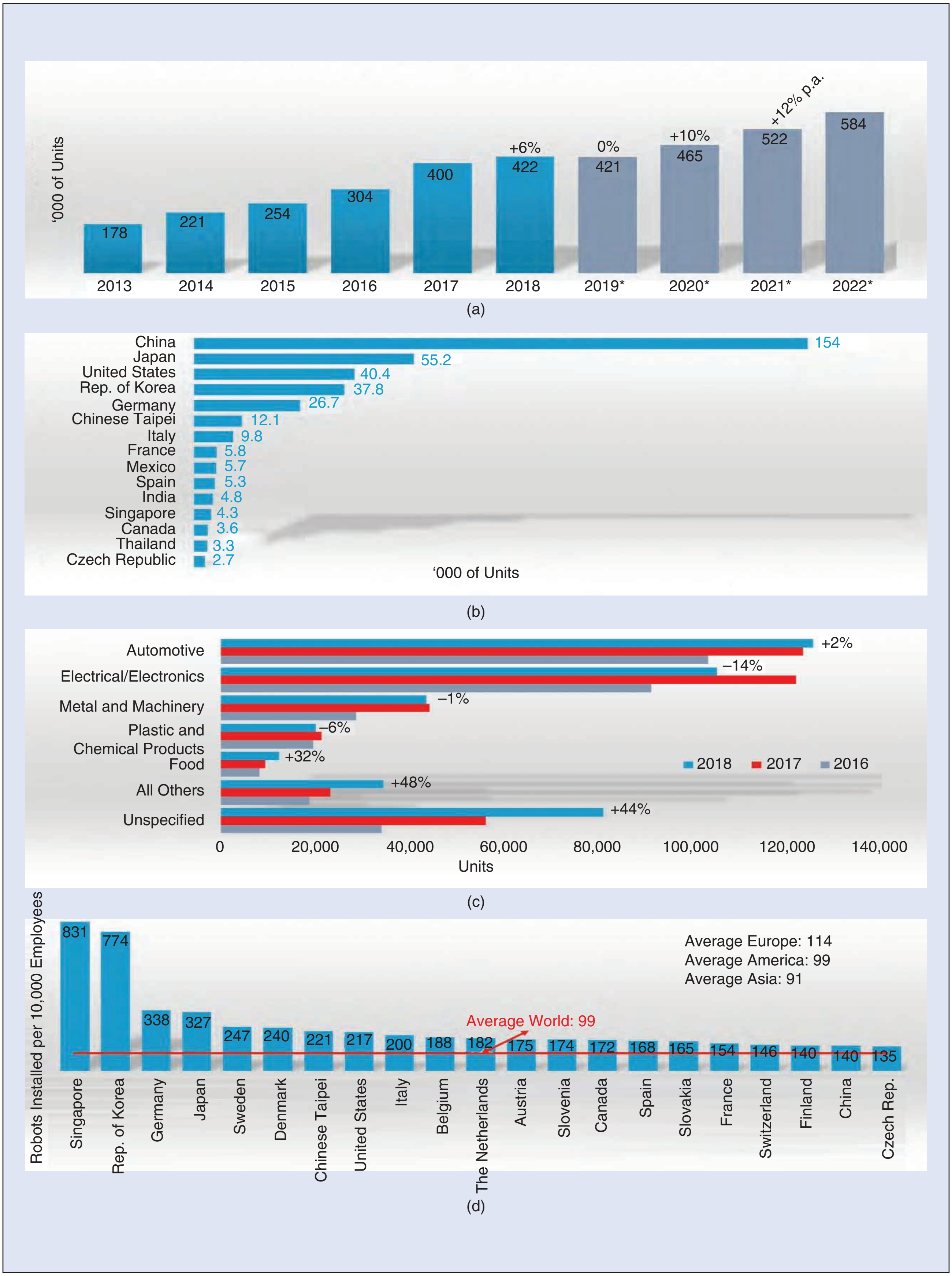

FIGURE 3 – The evolution of industrial robot installation in absolute and relative numbers per (a) year and (b) country and (c) industrial field and (d) per number of employees. (a) Robot installation evolution (*forecasted). (b) Robot installation per country. (c) Robot installation by industry type. (d) Robot density per country. (Source: World Robotics 2019; used with permission.)

industrial manipulators were (and still are) closed in working cells, with doors equipped with safety devices that cause an immediate stop of the robots if opened [Figure 4(a)].

The 2000s were characterized by the first approaches allowing robots and human operators to partially share the same spaces [5], mainly through supervision solutions including the prediction of human behavior [6] and the use of proper sensor systems [7]. In that period, the necessity of opening the cages in which the robots were enclosed to allow some initial form of human–robot collaboration was also addressed by the international ISO 10218 safety standards. The main issues addressed by such standards refer to the possibility of using safety-rated soft limits as a means to define and reduce the workspace of a manipulator as well as the adoption of devices that can initiate the reduction of the robot velocity or its full stop through the robot control system. Solutions based on industrial sensors, like the SafetyEYE by Pilz [8] and ad hoc safety devices, were developed to allow the human operator to enter the robot workspace in a safe manner [Figure 4(b)].

Safety concerns were also among the reasons why, in the past, industrial communications were not used for the coordination of robots. Classical fieldbus systems were sufficient for basic information and data exchanges (e.g., for start/stop commands), but each robotic cell worked independently with local control and local safety mechanisms. The communication system provided an interface to supervisory control and data acquisition systems, but it was not used for the actual real-time control of the robot.

In recent years, collaborative robots (cobots) are becoming part of the most advanced manufacturing plants to guarantee not only high levels of safety but also flexibility in production. The introduction of cobots represents a significant pillar of robotics in the Industry 4.0 scenario, which is going to deeply change the manufacturing and production processes. The International Federation of Robotics [9] noticed an increase of the ratio between collaborative and traditional industrial robots from 2.8% in 2017 to 3.4% in 2018.

The greater the diffusion of cobots in industries, the greater the importance and influence of human–robot collaboration (HRC) modalities. A recent interesting survey on HRC in industrial settings is available in [10], whereas a quite complete overview of HRC interfaces and interaction modalities is provided in [11]. There are, however, main gaps that are still open. 1) Only lightweight robots are used in most of the current HRC collaboration scenarios, thus losing the original vision of robots as high-powered machines. 2) Safety functionalities can sometimes obstruct the workflow, thus leading to inefficiencies. 3) More dynamic monitoring approaches would be needed to ensure that the workspace is adjusted according to the actual status of the robot and the task that it is performing. 4) The layout of collaborative robotic cells should be enhanced, not only to optimize the production workflow but also to increase the operators' feelings of safety and comfort.

The most challenging issues refer to the possibility of establishing a safe and efficient collaboration between humans and robots that were not originally built as collaborative ones. A recent article [12] investigates how to combine the benefits of high payload industrial robots with human capabilities in a fenceless environment through the adoption of enabling technologies, like manual guidance techniques (based on a force/torque sensor directly attached to the robot's flange) and wearable devices [such as augmented reality (AR) glasses and smartwatches], for a multimodal interaction. In other solutions available in the literature, safety is achieved through a synergistic use of safe and unsafe sensors. For example, in [13], the developed dynamic safety architecture detects human motions by two separate systems. The primary one is based on a generic human detection sensor system (e.g., Microsoft Kinects), while the secondary system is based on an actual safety sensor.

TABLE 1 – THE TYPICAL ROBOT OPERATIONS.

OPERATIONS	HIGHLIGHTS
WELDING Arc welding, flux cored welding, laser welding, metal active gas welding, metal inert gas welding, tungsten inert gas welding, orbital welding, oxyacetylene welding, other (plasma, ultrasound) welding, resistance welding, shielded metal arc welding, spot welding, submerged arc welding	• Spot welding is one of the most common welding applications in manufacturing. • All arc-welding processes use an arc welding gun or torch to transmit the welding current from a welding cable to the electrode.
MATERIAL HANDLING Collaborative operations, dispensing, injection molding, machine loading, machine tending, material handling, packaging, palletizing, part transfer, pick and place, press tending	• There exists a huge variety of palletizing and material-handling robots available in the market, with very different payloads and tools, like bag grippers, suction, and magnetic grippers.
MACHINERY Cutting, deburring, drilling, foundry, grinding, material removal, milling, polishing, refueling, routing, sanding, spindle, and waterjet	• Injection foundry was the first robotized task in 1960. • The preferred technology for cutting metal and plastic is laser cutting. Among the different laser types, the most used are gas, crystal, and fiber lasers.
DISPENSING Painting and enameling, bonding/sealing, coating, gluing, thermal spray	• Automated painting applications require specialized equipment to achieve accurate and consistent paint finish quality. • Sealing robots have built-in additional fluid handling technologies and numerous arm configurations to easily access any area of the part to seal.
OTHER ROBOT OPERATIONS 3D laser vision, assembly, mounting, inserting, cleaning	• The introduction of robotized assembly lines can exponentially increase the production rate, consistency, and reliability.

Haptic technology also plays an important role in robot safety and virtualization of services. An experience of touch by applying forces, vibrations, or motions to the user can be created with virtual objects in a computer simulation to control virtual objects and to enhance the remote control of machines and devices. Haptics is transforming robotic surgery in recent years [14] through the adoption of haptic devices in various applications, from laparoscopic and microsurgery to instrument positioning, needle insertion, palpation, and tissue stiffness mapping. The use of haptic devices in industry was traditionally mainly restricted to teleoperation tasks, in which the user moved within the virtual or remote environment by using the robotic device, and haptic feedback allowed computer simulations of various tasks to relay realistic and tangible sensations to the user.

Innovative solutions have been recently proposed, e.g., a completely remote human–robot collaboration system in [15] that can flexibly work in different

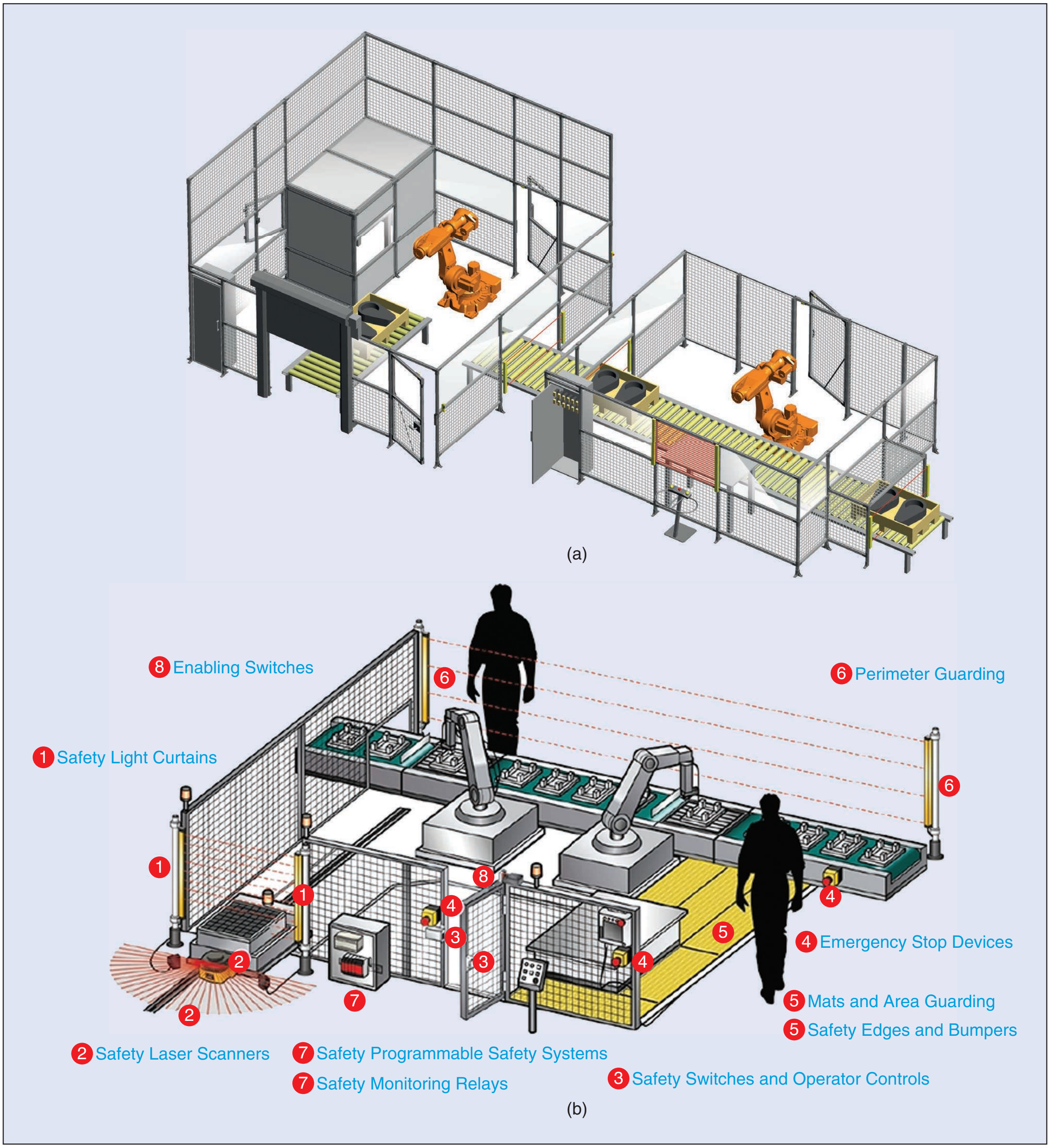

FIGURE 4 – (a) No human operator can enter the cages of traditional robotic cells. (Source: ABB Group; used with permission.) (b) Synergetic use of various safety devices allows human operators to enter the robot workspace. (Source: Valin/OMRON; used with permission.)

modes with the use of a collaborative robot and an industrial manipulator for hazardous tasks or through the use of vibrotactile rings. In [16], such a type of device is used to send acknowledgments to the user during critical phases of a collaborative assembly task. In [17], a bilateral haptic collaboration is established using a soft gripper that is properly designed to guarantee a safe interaction and a wearable interface to control the open/close motion of the gripper and to feedback information about the important task parameters, e.g., the grasp tightness. Such a solution has been successfully adopted in a complex collaborative task in which a robot autonomously grasps a pipe on which the human operator has to draw some circles before it is deposited in the final location by the robot.

Robotics in Industry 4.0

Robotics is going to play a key role in the smart factories that will benefit from the main design principles of Industry 4.0 [18], such as interoperability, decentralization, real-time capability, virtualization, service orientation, and modularity. The distinction between industrial and service robotics will no longer be as sharp as in the past since the technologies traditionally adopted in the service robotics world are migrating into manufacturing plants to allow for the development of new kinds of production lines [19].

The main elements of the production line (i.e., the industrial manipulators) are going to be replaced or placed side by side with cobots, whereas mobile manipulators (i.e., robotic arms on mobile bases) are expected to render obsolete the classical idea of an industrial robot being strictly associated with a fixed and caged manipulator. Nowadays, autonomous mobile robots (AMRs) are entering factories and taking on various roles on the basis of the specific requirements, e.g., to autonomously cooperate with other smart devices and factory workers as a unique team [20] or to act as a metasensor network supporting traditional automated guided vehicles (AGVs). AMRs, cobots, enhanced manual stations, full integration within the automated lines, and mobile manipulators will be the pillars of Industry 4.0 plants, as illustrated in Figure 5, although the most critical challenge in the industrial world is going to be the achievement of a smooth transition from the current industrial standards.

The role of the traditional AGVs is changing as well. Since the introduction of AGVs in 1953, technology has greatly evolved in those devices, leading them to behave as autonomous robots, able to navigate and follow a predefined, specific path for the material flow pattern. The new ability to plan trajectories and pathways allows for the optimization of routes and the enhancement of goods transportation

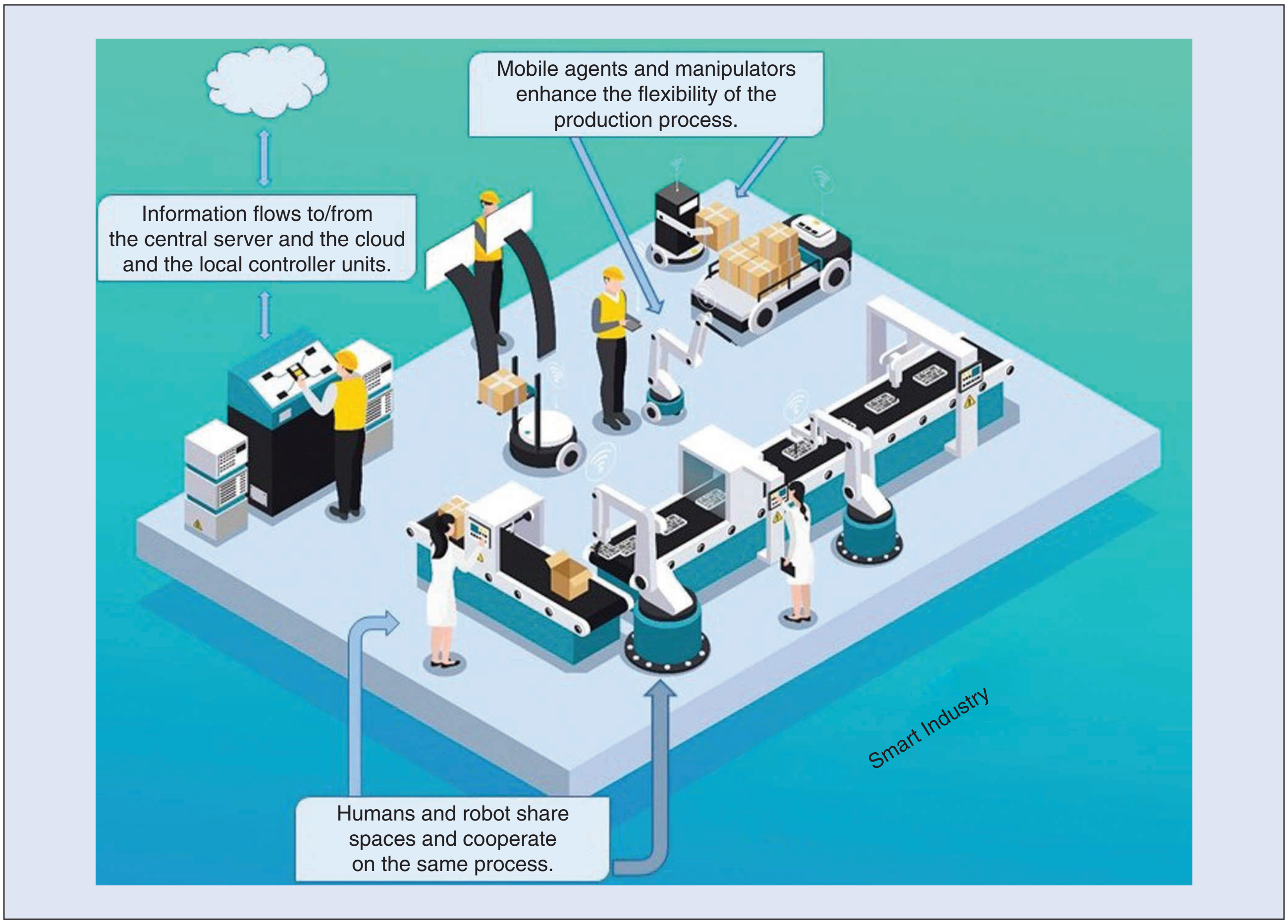

FIGURE 5 – A smart factory. No cages are present: cobots, AMRs, and humans share the same space. (Source: Adapted from FreePik.com.)

in the plant while applying robust collision-avoidance procedures.

All of these AGVs carry on-board intelligent sensors that make the robot react in front of any unexpected change in the environment. Those sensors are based mainly on radio-frequency identification [21] and rotating laser and computer vision [22]. Simultaneous localization and mapping (SLAM) navigation technology, which allows mobile robots to locate themselves while building a map of the surrounding environment using sensors like lidar, cameras, and odometry, is mature enough to be deployed to AGVs. The collision-avoidance function of lidar can be adopted for the intelligent multilevel obstacle avoidance protection during motion [23]. SLAM is, right now, the navigation mode chosen by many AGV manufacturers, and large e-commerce businesses, such as Ali and Amazon, already use AGVs as storage robots. In the Industry 4.0 scenario, advanced data communication is fundamental for not only the safe operation of collaborative robots [24], [25] but even more so for AGVs and multirobot handling and coordination [26]–[28] as they have to cope with strict requirements of mobility, reliability, and bounded latencies.

A proprietary technology available today for supporting AGVs' management over wireless links is the Siemens industrial wireless local area network (iWLAN) that provides support to real-time traffic in large industrial areas. Exploiting a time-division multiple access-based scheme, iWLAN provides deterministic access with controlled jitter and roaming switchover time on the order of 20–30 ms, thus allowing for the real-time management of a number of AGVs over large areas.

The need to transfer huge quantities of information in a fast and reliable way will demand more advanced communication methods. Current industrial communication infrastructures may reach their limits in terms of bandwidth, supported nodes, and end-to-end response times, thus drawing extensive research interest to technologies that meet the increasingly stringent requirements of specific industrial applications. IoT and cyber-physical system (CPS) concepts have already initiated a radical change in the way industrial communication is viewed today [29]. 5G networks could be a further step toward providing a ubiquitous communication infrastructure that can be used as a commodity. Moreover, 5G technology would natively support mobile devices.

Another aspect of Industry 4.0 is the digitalization and virtualization of services. This is highlighted by the concept of "digital twins," where each physical entity (such as a robot) has a virtual counterpart exhibiting all of the properties and data of the real device. This twin offers services that can be used by other virtual devices or by higher-level applications, e.g., for production optimization or improving collaboration. The digital twins are executed in some back office cloud environment providing sufficient computing power. As depicted in Figure 6, this results in a three-level service architecture typical for the Industry 4.0 idea.

Last but not least, the development of the smart factories scenario is accompanied by the introduction and application of the concept of robotics as a service. More and more often, startup companies collaborate with factories, warehouses, and distribution centers, providing services instead of products. Most of these products are oriented to the integration of smart sensors as well as technologies that are more familiar to service robotics than industrial ones (e.g., the use of unmanned aerial vehicles to collect data to be processed and integrated into large processes). Although the increasing number of robots in manufacturing plants could reduce the number of human operators directly involved, the growing automation of processes has a positive effect on employment, on the whole, thanks to the involvement of various actors providing different services and the reduction of the production costs, leading to lower market prices, as already noticed in the automotive sector in Germany [30].

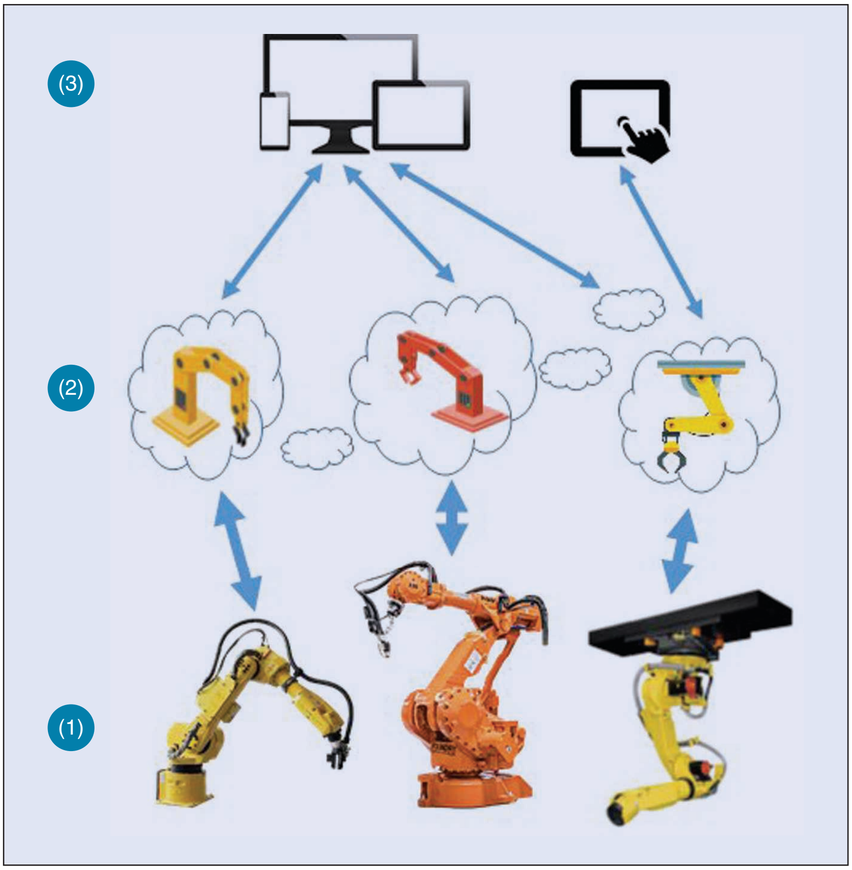

FIGURE 6 – The three-level hierarchy in Industry 4.0: the physical devices (1), their digital twins (2), and the service level (3). Communication is based on Internet technology and the IoT paradigm.

Future Directions and Open Issues

The smart factories of the very near future will see a high presence of industrial robots, not only for large-scale manufacturing as usual but also in versatile production processes, e.g., in SMEs, whose productions are characterized by a strong commitment to continuously adapting to customer requests and meeting the market demands. In this scenario, the possibility of having both manipulators and mobile agents, acting in a coordinated way, sharing the same spaces, and collaborating with the human operators, is very appealing [31]. Multirobot coordination addresses several well-known issues, the correct management of which firstly relies on the proper software and hardware architecture. Starting from the popular Robotic Operating System (ROS), which enables the implementation of complex and robust robot behaviors across a wide variety of robotic platforms, a new initiative of ROS–Industrial has been launched as an open source project that extends the advanced capabilities of ROS software to manufacturing [32]. Software is one aspect only, even if it is important; the evolution of robotics will depend upon a wide range of innovative technologies and require inputs from diverse fields.

New Materials

In the next years, the research promises new materials for a new generation of robots, i.e., smart materials for soft robots, which will be able to add new features and capacities to robotics. The new materials can be hard, as piezomaterials [33]; flexible, as in alloys with shape memory; soft, as in dielectric elastomers [34]; or even fluid, as in ferrofluids and electrorheological fluids, which change their shape in front of electrical fields [35]. The idea of deploying soft robots in industry is not new, although the term has evolved with the latest developments in robotics. Soft no longer means deformable and not built with rigid elements. The new concept for soft refers to a new generation of robots with an almost muscular deformation, built with polymers similar to bones, and with muscles and actuators similar to gas bladders. These materials are cheap, resilient, and based on existing technology.

The research goal in the field of new materials is the replacement of the metallic and rigid robots with smooth, soft robots that could be friendlier when interacting and collaborating with humans. For instance, the magnetic liquid metal droplet introduced in [36] can be stretched in large scales both horizontally and vertically. Such a remarkable stretching capacity is reversible, long lasting, and can be repeated multiple times. In [37], a team of researchers created smart and biodegradable materials for robots that can be broken down and do not pollute the environment. The plastic is replaced by bioplastic made of food waste with a low-energy process, and the stiffness of the material is suitable for external robot parts. With such materials, robot arms and androids would resemble humans, and their bodies would decompose at the end of their life cycle as if they were flesh and blood persons.

New Sensors and Actuators

Sensorial capabilities are fundamental for any robotic application. A recent overview of the most common types of sensors (e.g., visual, laser, tactile sensors, and so on) for industrial robots can be found in [38]. The growing adoption of collaborative robots is pushing toward the introduction of advanced tactile skin sensors to be attached to the robot's surface to guarantee the human operator's safety. Examples can be found in the literature, e.g., in [39], but some commercial devices are also available, such as the Kuka collaborative robot series [40]. Such solutions allow the detection of contact pressure, but they cannot predict a possible impact in advance. To enhance safety, the most recent trends are toward the development of proximity skin sensors able to detect an object before any contact happens, e.g., capacitive sensors as in [41] or robotic skin modules as in [42], allowing for the measurement of proximity, contact, and force through an array of optical sensors. A further solution has been recently proposed in [43], employing time-of-flight sensors able to detect the object's position and its approximate shape before contact.

The adoption of robots in new application scenarios often relies on the use of innovative grippers [44] that are able to successfully perform assembly and picking tasks involving "critical" items, like small and flat objects, for which suction cup grippers may fail if the objects are too lightweight and fragile. Innovative solutions have been recently proposed, e.g., in [45] and [46], where passive and epicyclical mechanisms are adopted to mimic the sliding motion of the human thumb below the object to be grasped. In the soft robot context, a soft gripper, made up of four prestressed actuators, was developed in [47] for food handling.

New Wearable Machines

A growing sector in the industrial scenario is represented by exoskeletons, thanks to decades of research, advancements in enabling technologies, and big investments. Exoskeletons can be divided into two categories, passive and active. Passive suits are fully mechanical and have no motors. They improve ergonomics and effectively distribute weight for their wearers. Their widespread adoption across big companies in automotive, aerospace, logistics, and construction constitutes an attractive market. Active robotic exoskeletons are a more ambitious technology. They use motors for actuation, enabling them to provide significant lift assistance to workers, thus reducing workforce injuries.

The industrial exoskeleton sector is still in its early age, and the market opportunity is very large. Some car manufacturers have started to include industrial exoskeletons in production lines, like Hyundai, Ford, and BMW. There are other niches for the growth of exoskeleton technology. In construction, manufacturing, agriculture, and other industries that are adopting robotic structures, exosuits augment human motion to allow for more lifting strength and improved production on repetitive tasks like squatting, bending, or walking [48], as seen in Figure 7. The market potential for industrial exoskeletons is as enormous as the rewards for entrepreneurial solution providers that can aggressively innovate and come to market with workable solutions delivering business value [49].

Issues Related to New Technologies

Apart from hardware-related aspects, there are also data- or information-related key points that characterize the factories of the future, like the integration of different actors at the various levels (from the software point of view up to the handling of the whole production process), sustainable energy consumption, safety issues, or social human–robot interaction aspects. The most recent trends consider the factory on the whole as a CPS [50], [51] in which the robotic systems play an important role. Their tasks are going to be modeled and programmed considering the overall production goals in terms of efficiency and quality to achieve high performance so as to facilitate the adaptation of the robot tasks to the frequent changes of the production process. In [52], a CPS approach is also adopted to establish a safe human–robot collaboration in a shared workplace.

A proper definition of the performance indicators to be optimized can also include energy consumption, which is of growing importance. Energy consumption reduction for a single robot is important and is achievable in different ways (see, e.g., [53] and the references therein). However, an overall energy optimization would be desirable for the entire robotic cell, e.g., as in [54], and for the management of the complete production process as well.

The possibility of performing collaborative assembly tasks is going to open brand-new application scenarios, but it also raises challenging safety and human–robot interaction social aspects. As discussed in [55] and some references therein, for a fruitful cooperation, the operator and the robot must understand the actions and intentions of each other, according to the following four functional specifications relevant to the operator's working experience:

1) *flexibility* (the operator should not be forced to follow a strict, predefined sequence of operations but should be allowed to change them on the fly)
2) *intelligibility* (the operator should be capable of intuitively understanding the robot actions and intentions through some form of communication)
3) *adaptability* (the robot should adapt to the operator's actions without requiring an operator-specific calibration process)
4) *transparency* (operators should not be forced to stay in a specific location all the time to safely collaborate with the robot).

An integrated architecture partially solving these problems can be found in [55], together with an interesting overview of other solutions in literature, but several issues are still open. For example, the use of AR devices, like smart glasses, included in several of the most advanced solutions, is not always welcome because the operator's field of view is limited, and their situational awareness could decrease. Other solutions have been recently proposed, like the one in [56], where a visual indicator system is developed to communicate the robot's status to the human operator.

Drivers and Barriers

The deployment of industrial robots still suffers from some barriers in an important part of the productive sector, i.e., the SME world. In the European Union, 91% of all employment corresponds to SMEs, as does 68.2% of all jobs in manufacturing [9]. However, such companies have not been widely adapted to robotic manufacturing. The main reasons why robotized solutions have not been adopted are discussed in [57] and summarized in Figure 8.

Companies often face two alternatives, i.e., either opt for current automation solutions, even if they are unsuited for low-volume and low-cost productions, or employ workers who perform the manufacturing process manually and thereby compete based on lower wages. Innovative robotic solutions should provide ways to tackle these barriers for SMEs, which are often impacted by low capitalization problems, difficult access to finance, lack

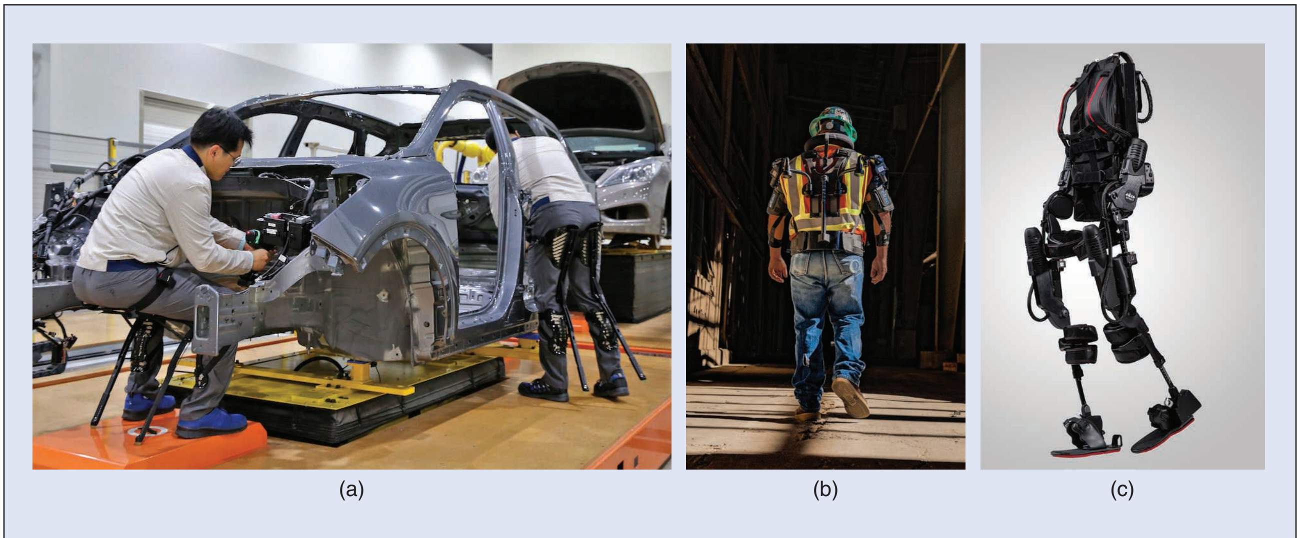

FIGURE 7 – (a) A chairless exoskeleton (H-CEX). (Source: Hyundai Inc.; used with permission.) (b) A back support exosuit. (c) A whole-body suit. (Source: EksoBionics; used with permission.)

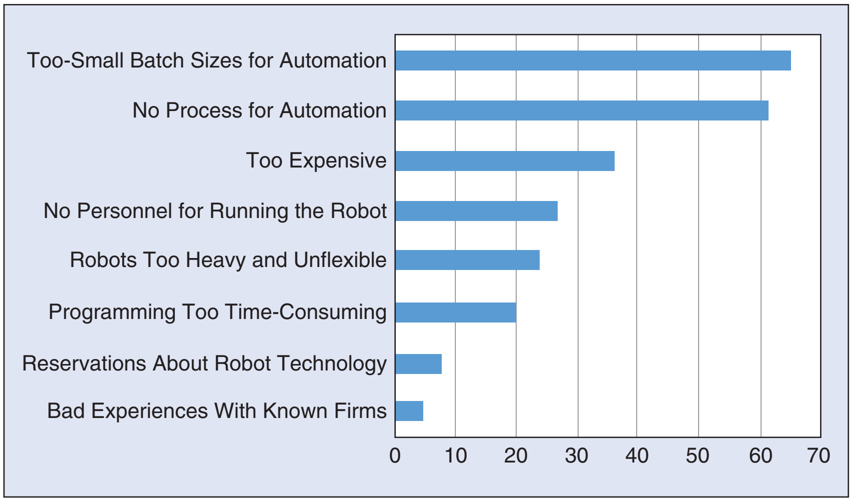

FIGURE 8 – Some reasons why SMEs do not use robots.

of awareness of the benefits of robotic solutions, low technical competence outside of the core business, and low capability for long-term investment.

The constant decrease of robotic technology costs plays an important role in the adoption of automation solutions by SMEs. Financial incentives for those companies, like leasing solutions and the refurbishment of robots, can also be a way to engage SMEs in robotic technology.

Today, there exist solutions offering financially attractive lightweight robots that can be easily moved from one industrial process to another depending on the production necessity by simply reprogramming them every time it is necessary. The final goal is to have user-friendly robotic solutions that do not require workers to have technical knowledge of robots or machine learning. In the short term, good prospects are envisaged for industrial robotic technology. Energy efficiency and new materials can attract the use of robots. The fast production of customized elements at competitive prices is also a good incentive to use this technology.

Some markets forecast an increasing demand, such as the metal and machinery industry, the rubber and plastic industry, and the food and beverage industry. Also, the electrical/electronics industry will have big demands. All of these elements anticipate a significant increment of robotized manufacturing processes in the short and midterm, not only for large companies but also for SMEs, which have the possibility of achieving a new competitiveness thanks to the most innovative robotic solutions.

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