Robots in Industry. Past,present and future of a growing collaboration with humans

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Robots in Industry

Past, present and future of a growing collaboration with humans

Abstract— Robots have been part of automation systems for a very long time, and in public perception, they are often synonymous for automation and industrial revolution per se. Fueled by the Industry 4.0 and Internet of Things 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 co-working and collaborative robots. The role of robotics in the Industry 4.0 framework is analyzed, discussing also the relationships with industrial communications and software technologies. 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 Enterprises world.

I. Introduction and Motivation

Along 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.)*, showing the 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 of human-like machines plays no significant role. Rather, robots have always been an element of automation, their main tasks being to relieve human workers from heavy, dangerous, or monotonous work and to improve product quality by increasing 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 towards 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 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, that permits 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 mobility of robots as well as the inclusion of sensors or actuators around the actual robot [4].

The purpose of this survey 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.

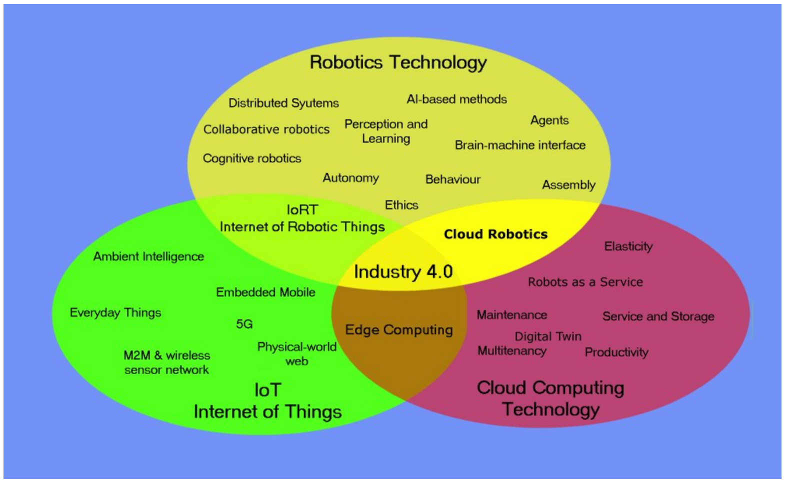


Figure 1. Technology fields influencing modern robotics.

II. A Taxonomy of Industrial Robots

Starting from the progenitors of robots, i.e., telemanipulators, Figure 2 shows a timeline of the evolution of industrial robotics together with some famous robots, and relevant milestones of technologies and sciences strictly related to robotics. 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 along the decades.

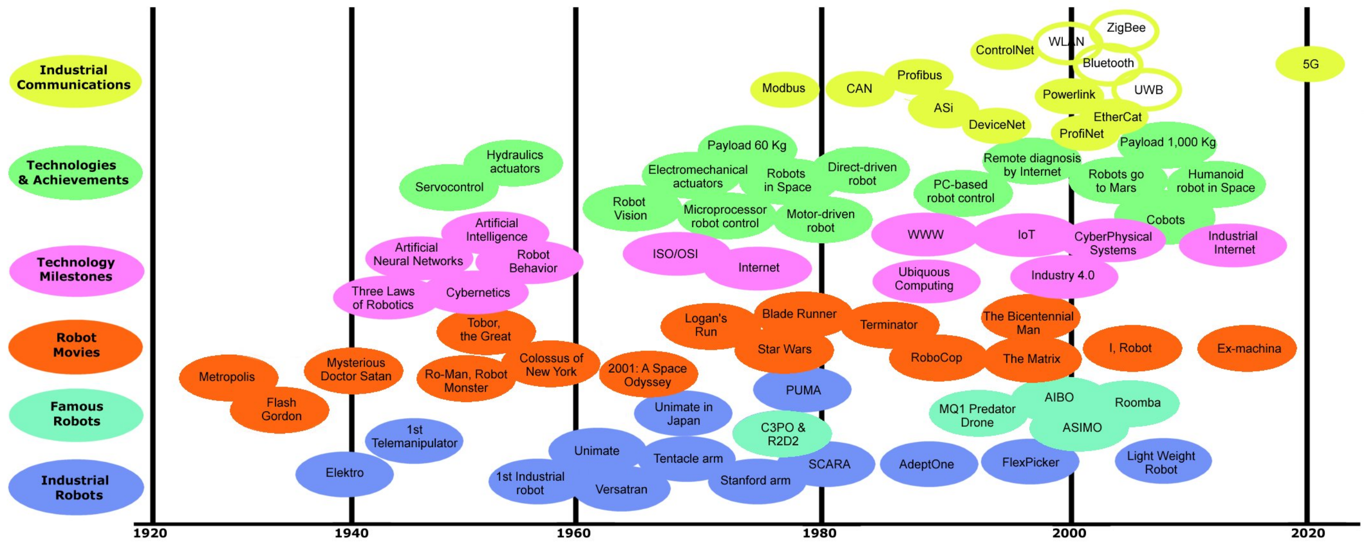
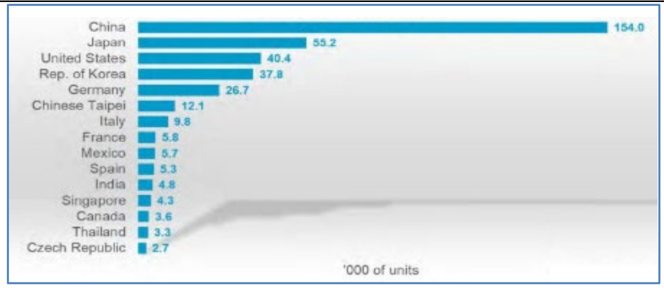


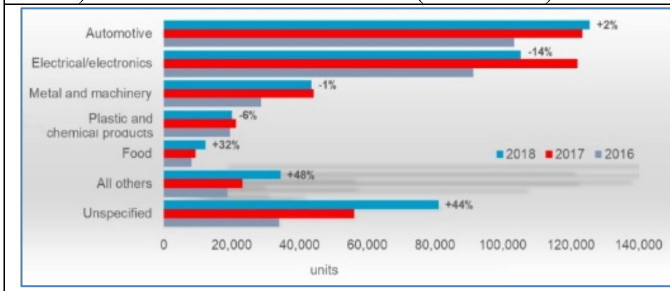
Figure 2. Timeline of some remarkable aspects in robotics.

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 last year in robots' installations in Asia, together with the still-emerging China production. Figure 3 also reports the robot density ranking, i.e., the number of deployed industrial robots per worker in various countries.

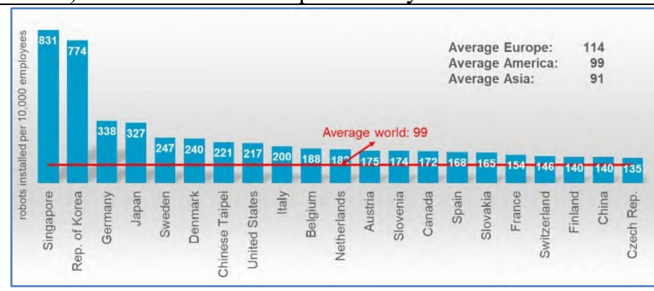
a) Robot installation evolution (*forecasted)



b) Robot installation per country



c) Robot installation by industry type



d) Robot density per country

Figure 3. Evolution of industrial robot installation in absolute and relative numbers per country and per industrial field (Source: World Robotics 2019).

Globally, the automotive industry leads the number of units installed in car and car supplies factories with an attractive 2% of 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 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 the last chart of Figure 3. As with the general industry, robot industry devoted to robot production foresees a huge increment for the next years.

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

Table 1. Typical robot operations

Operations	Highlights
Welding Arc Welding, Flux Cored Welding, Laser Welding, MAG, MIG, TIG and 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 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, 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.

III. From isolated to co-working 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 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, left).

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 the human behavior [6] and the use of proper sensor systems [7]. In that period, the necessity to open the cages in which the robots were closed, 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, right).

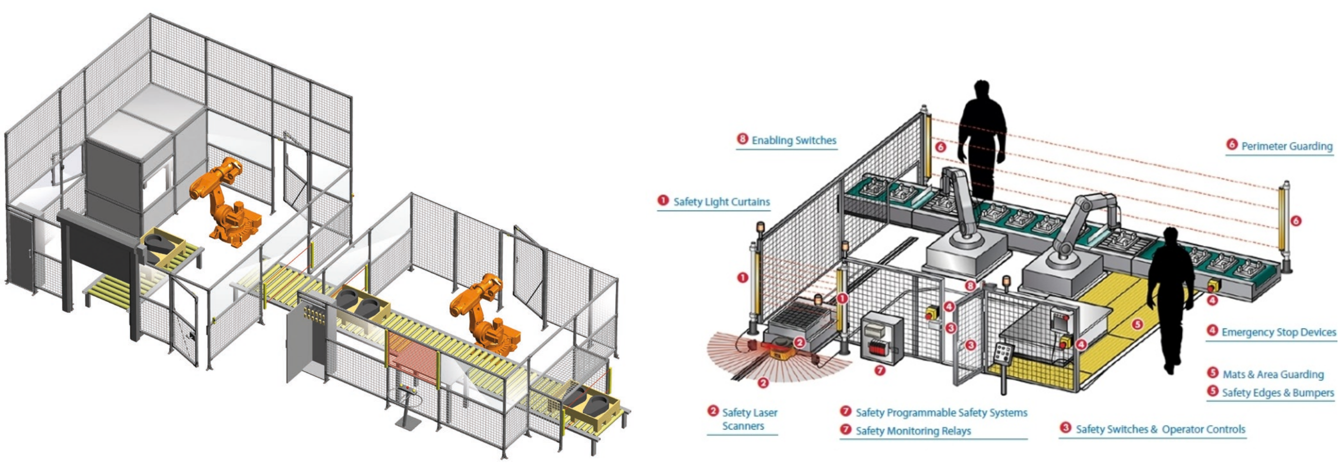


Figure 4. Left: No human operator can enter the cages of traditional robotic cells (Image source: https://new.abb.com – See the copyright notice in the website for permission to use). Right: Synergetic use of various safety devices allows human operators to enter the robot workspace (Image source: https://www.valin.com - Courtesy of OMRON)

Safety concerns were also among the reasons why in the past industrial communications were not used for 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 SCADA systems, but it was not used for the actual real-time control of the robot.

In the most recent years, collaborative robots (cobots) are becoming part of the most advanced manufacturing plants, just to guarantee not only high levels of safety, but also of flexibility in the production. The introduction of cobots represents a significant pillar of robotics in the Industry 4.0 scenario, that 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: i) only lightweight robots are used in most of the current HRC collaboration scenarios, thus losing the original vision of robots as high powered machines; ii) safety functionalities can sometimes obstruct the workflow, thus leading to inefficiencies; iii) 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; iv) the layout of collaborative robotic cells should be enhanced, not only to optimize the production workflow, but also to increase the operators' safety feeling 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 paper [12] investigates how to combine the benefits of high payload industrial robots with human capabilities in a fenceless environment, also 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 glasses and smartwatches), for a multi–modal 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 (for example Microsoft Kinects), while the secondary system is based on an actual safety sensor.

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 remote control of machines and devices. Haptics is transforming robotic surgery in the most recent years [14], through the adoption of haptic devices in various applications, from laparoscopic and microsurgery to instrument positioning, needle insertion and palpation, and tissue stiffness mapping. The use of haptic devices in industry was traditionally mainly restricted to teleoperation tasks, in which the user moves within the virtual or remote environment by using the robotic device, and haptic feedback allows computer simulations of various tasks to relay realistic and tangible sensations to the user. Innovative solutions have been recently proposed, e.g., for a complete remote human–robot collaboration system in [15], that can flexibly work in different 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 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, 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 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.

IV. 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 be no longer as sharp as in the past, since the technologies traditionally adopted in the service robotics world are migrating into manufacturing plants, to allow 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 the factories, taking 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 meta-sensor network supporting traditional automated guided vehicles (AGVs). AMRs, cobots, enhanced manual stations, fully integrated within the automated lines, and mobile manipulators will be the pillars of Industry 4.0 plants, as sketched 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.

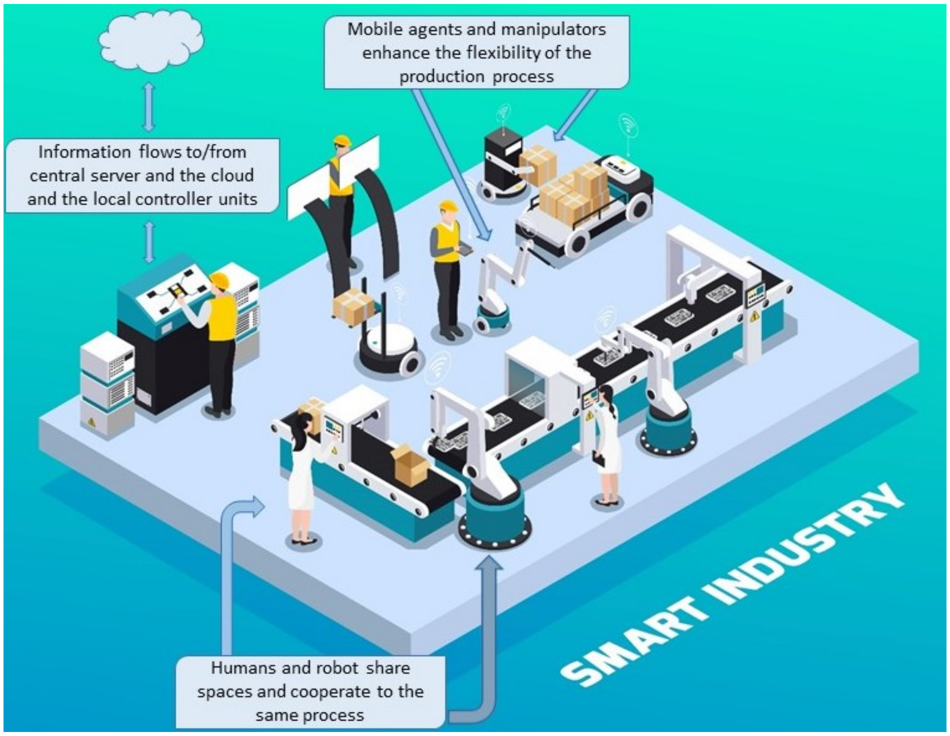


Figure 5. Sketch of a Smart Factory. No cages are present: cobots, AMRs and humans share the same space (Image source: Elaborated from FreePik.com)

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 to optimize routes and enhance the goods transportation in the plant, while applying robust collision avoidance procedures.

All 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 RFID [21], rotating laser and computer vision [22]. The SLAM (Simultaneous Localization and Mapping) 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 multi-level 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 for AGVs and multi-robot 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 WLAN (iWLAN) that provides support to real-time traffic in large industrial areas. Exploiting a TDMA-based scheme, iWLAN provides deterministic access with controlled jitter and roaming switchover time in the order of 20–30 ms, thus allowing for 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, drawing extensive research interest to technologies that meet the increasingly stringent requirements of specific industrial applications. IoT and CPS concepts have already initiated a radical change in the way industrial communication is viewed today [29]. 5G networks could be a further step towards 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 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 shown in Figure 6, this results in a three-level service architecture typical for the Industry 4.0 idea.

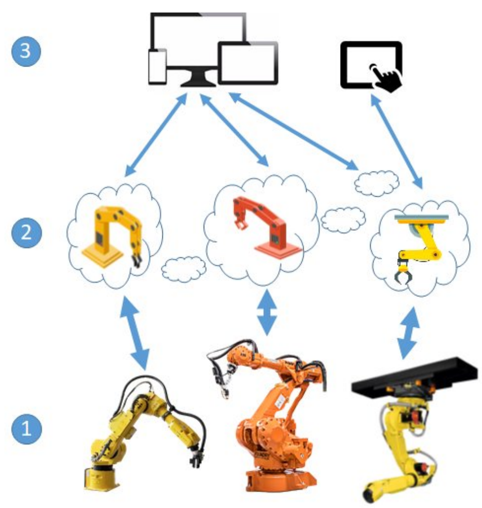


Figure 6. Three-level hierarchy in Industry 4.0: The physical devices (1), their digital twins (2), and the service level (3). Communication is based on Internet technology and the IoT paradigm

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 (RaaS). More and more often startup companies collaborate with factories, warehouses and distribution centers, providing services instead of products. Most of those products are oriented to the integration of smart sensors, as well as of technologies that are more familiar to service robotics than the industrial one (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 the 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].

V. 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 Small and Medium Enterprises (SMEs), whose productions are characterized by the strong commitment of continuously adapting to customer requests and meeting the market demands. In this scenario, the possibility of having both manipulators and mobile agents, acting in coordinated way, sharing the same spaces and collaborating with the human operators is very appealing [31]. Multi-robot coordination addresses several well-known issues, whose correct management firstly relies on a proper software and hardware architecture. Starting from the popular Robot 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 only one aspect, even if important: the evolution of robotics will depend on a wide range of innovative technologies and require inputs from diverse fields.

A. *New materials*

In the next years, research promises new materials for a new generation of robots, i.e., smart materials for soft robots, able to add new features and capacities to robotics. The new materials can be hard, as piezomaterials [33], flexible, as the alleys with shape memory, soft, as dielectric elastomers [34], or even fluid, as 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 last developments in robotics. Soft does not mean deformable, but not built with rigid elements any longer. The new concept for soft refers to a new generation of robots with an almost muscular deformation, built with polymers similar to bones, but with muscles and actuators similar to gas bladders. Those 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 (MLMD) 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.

B. *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, etc.) for industrial robots can be found in [38]. The growing adoption of collaborative robots is pushing towards the introduction of advanced tactile skin sensors to be attached to the robot's surface to guarantee the human operator safety. Examples can be found in the literature, e.g., in [39], but also some commercial devices are available, such as the Kuka collaborative robot series [40]. Such solutions allow the detection of the contact pressure, but they cannot predict a possible impact in advance. In order to enhance safety, the most recent trends are towards 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 to measure 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], 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 robots' context, a soft gripper, made up of four prestressed actuators, was developed in [47] for food handling.

C. *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, 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 exoskeleton in production lines, like Hyundai, Ford and BMW. There are others niches for exoskeletons' growth. In construction, manufacturing, agriculture, and other industries that are adopting robotic structures, the exo-suits augment human motion to allow for more lifting strength and for improved production on repetitive tasks, like squatting, bending, or walking [48], as it is shown 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].

Figure 7. Left: Chairless exoskeleton (H-CEX) (Image source Hyundai Inc.); Middle: Back support exosuit; Right: Whole-body suit (Image source: EksoBionics).

D. *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 next 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 Cyber-Physical System (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 adopted also to establish a safe human-robot collaboration in a shared workplace.

A proper definition of the performance indicators to be optimized can also include the 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 raises also challenging safety and human-robot interaction social aspects. As discussed in [55] and in 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: i) *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); ii) *intelligibility* (the operator should be capable of intuitively understanding the robot actions and intentions through some form of communication); iii) *adaptability* (the robot should adapt to the operator's actions without requiring an operator-specific calibration process); and iv) *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 operators' field of view is limited and the situation 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.

VI. DRIVERS AND BARRIERS

The deployment of industrial robots still suffers from some barriers in an important part of the productive sector, i.e., the SMEs world. In the EU, 91% of all employment corresponds to SMEs and 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.

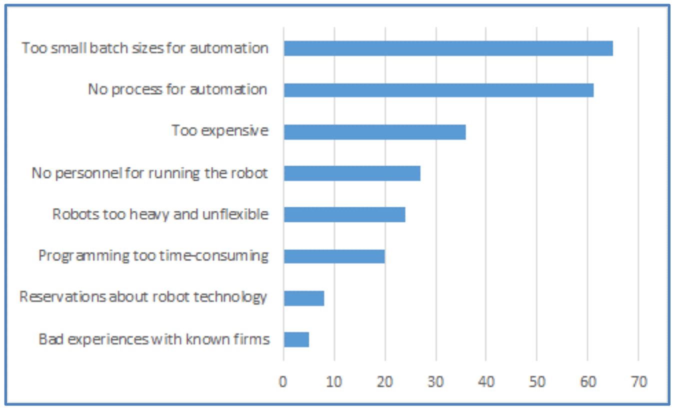


Figure 8. Reasons why SMEs do not use robots.

Companies often face two alternatives, i.e., either to opt for current automation solutions, even if unsuited for low-volume and low-cost productions, or to employ workers that perform the manufacturing process manually, and compete based on lower wages. Innovative robotic solutions should provide ways to tackle these barriers for SMEs, which are often affected by low capitalization problems and difficult access to finance, lack of awareness of the benefits of robotic solutions, low technical competence outside 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 refurbishment of robots, can also be thought to engage SMEs in the 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, 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 a short term, good prospects are envisaged for industrial robotic technology. Energy-efficiency and new materials can attract the use of robots. 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 metal and machinery industry, rubber, plastic industry and food and beverage industry as well. Also, electrical/electronics industry will have big demands. All these elements anticipate a significant increment of robotized manufacturing processes in the short and mid-term, not only for large companies, but also for SMEs, which have the possibility of achieving a new competitiveness just thanks to the most innovative robotic solutions.

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