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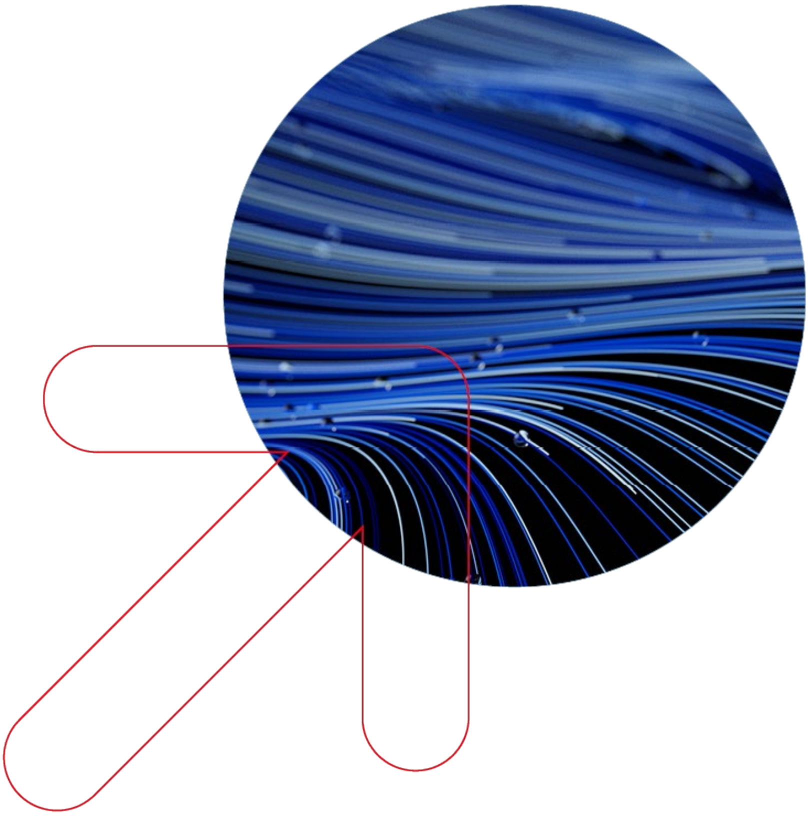

The impact of innovative digital technologies on the market for industrial robotics applications

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Table of contents

List of figures

Summary

Digital technologies have been relevant in the market for industrial robotics for several decades, as software for robot control represents a key enabler for the development of industrial robots. The developers and manufacturers of traditional industrial robots are global players such as KUKA or FANUC who typically purchase hardware and software from third parties and have their robots implemented by system integrators. A wide range of market players with a high degree of specialisation are active as component suppliers and system integrators.

Robotics applications have become highly important for the efficiency of production processes in large-scale production, particularly in the automotive industry. For small and medium-sized (SME) companies, however, there is a lack of robotic applications that can fulfil their specific requirements for simple implementation and usage, low costs and flexible operation.

Innovative digital technologies are leading to changes in the robotics market, which are primarily based on their expanded options for data generation (using sensors), processing (using software/AI), storage (e.g. via cloud/edge) and transmission (e.g. 5G).

The potential of digitalisation is predominantly used by a variety of new players. It helps to simplify the implementation and use of robotics, to handle more complex tasks and a high product diversity and to enable a close and safe cooperation between robots and humans. These developments may also increase the demand of SMEs' for robotic services.

Connectivity is a precondition for some of these new developments. For example, mobile autonomous robots are a new robot variant in the field of professional service robotics that is based on wireless connectivity. They also play a crucial role in the (vision of a) smart factory, which will rely on completely connected machines, systems and processes.

The changes in industrial robotics enabled by innovative digital technologies are taking place gradually and, unlike in many other markets, have not yet led to disruptive developments that threaten existing business models. Instead, they are gradually creating additional revenue potential for the benefit of a wide range of players in the robotics ecosystem.

1 Introduction

The market for industrial robotics applications is characterised by decades of growth, which was primarily generated by offerings for large-scale production. In Germany, in particular large automotive manufacturers use robots as part of comprehensive automation solutions to increase efficiency and strengthen their global competitiveness. For small and medium-sized user companies, however, suitable robotics applications are lacking, which take their specific requirements regarding an easy implementation, low costs and flexible usage options into account.

Changes in the robotics market have been emerging for several years now, enabled in particular by innovative digital technologies. Suppliers in the robotics market take the opportunities offered by the progress in the areas of sensor technology, software/AI, cloud/edge and wireless connectivity to develop completely new robotic offerings as well as to develop existing robotics applications further.

This study analyses the trends in the market for industrial robotics applications driven by innovative digital technologies, and deals with the associated changes in the robotics eco system.

A multi-stage research approach was chosen to ensure well-founded and balanced study results:

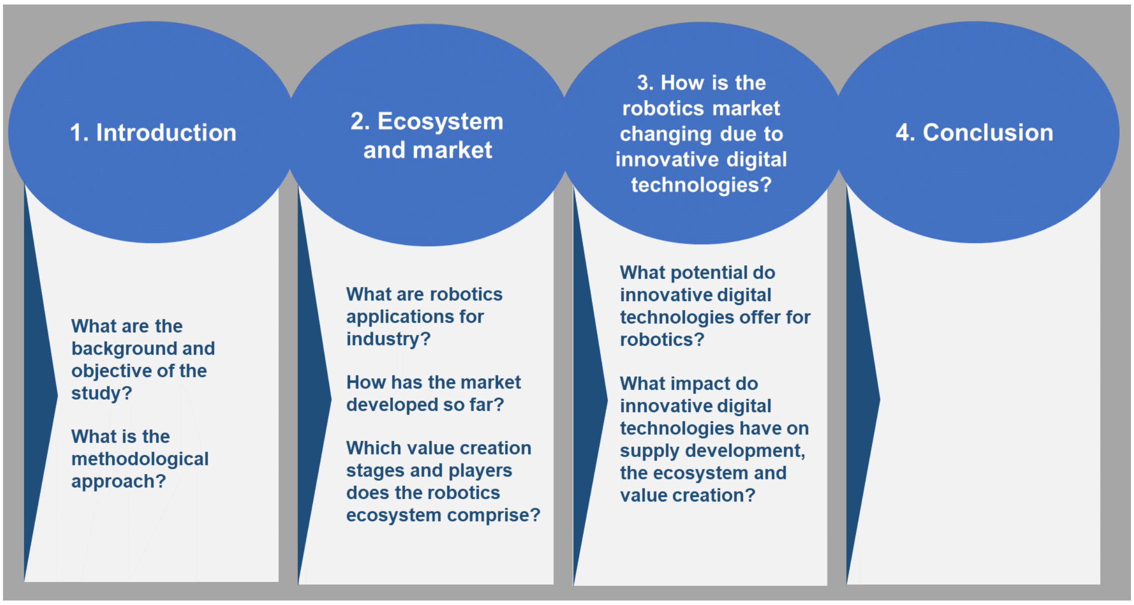
- **Desk research**: Publicly available studies, statistics, articles and other relevant publications were analysed in order to set relevant priorities and to identify potential interview partners and workshop participants.
- **Expert interviews**: More than 20 qualitative interviews were conducted with representatives of suppliers, users, research institutions and other stakeholders in order to consider the different perspectives on the role of digitalisation for industrial robotics applications. These took place in the first half of 2023 via video conferences and in person at the automatica trade fair in June 2023.
- **Workshop**: On 11 May 2023, a virtual workshop was held on the topic of "Digitalisation of robotics applications for industry". Over 50 representatives from politics, supplier and user companies, associations, institutions relevant to SMEs and authorities discussed potentials and challenges of the industrial use of robotics applications.

The study is structured as follows (see Figure 1-1):

Chapter 2 lays the **basics for understanding the ecosystem and the market for industrial robotics applications.** Robotics applications for industry are explained in terms of definitions. The status quo of the market is depicted on the basis of publicly available data. Then, the robotics ecosystem is presented to provide an overview of the relevant value creation stages and stakeholder groups.

Chapter 3 focuses on the **role of innovative digital technologies for the robotics market.** After a brief introduction on the general opportunities, key market trends are defined and analysed. Based on the current market situation, it is shown which innovative digital technologies enable the respective market trend and how this is reflected in new robotics applications. Each market trend is also analysed in terms of its potential impact on the robotics value creation system. In addition, selected examples are used to show how providers of robotics applications are using the opportunities of digitalisation for their business models.

Figure 1-1: Structure of the study



Source: WIK

2 Ecosystem and market for industrial robotics

2.1 What are robotics applications for industry?

The term "robot" is often used as a collective term for a broad spectrum of machines and applications, ranging from chatbots to self-driving cars and armed drone aircrafts.

In the narrower sense, the term robotics refers to physical devices or machines that can be programmed to perform tasks automatically.

Robots can also be enabled to carry out work largely autonomously, requiring only very limited human intervention. This is made possible by appropriate interaction of the robot with the environment, which is technically realised, for example, on the basis of sensors, actuators and information processing.[1] This definition already indicates the high relevance of digital technologies (in the form of hardware and software) for robotics.

Based on technical criteria, robots can be divided into industrial robots and service robots.[2] The ISO (International Organization for Standardisation)[3] has made this distinction for the development of standards. It is also used by the IFR (International Federation of Robotics[4]) when compiling statistics on the robotics market (see chapter 2.2). [5]

Industrial robots can be used for a wide range of tasks, the definition of which is not always clear:

- Handling: loading and removing handling objects, picking up and moving objects, palletising, stacking and packing
- Assembly: assembly of components
- Joining: acrewing, welding, soldering, gluing, cutting
- Surface treatment: painting, sanding, polishing, enamelling
- Cutting
- Quality control, measuring, testing and inspection

The focus is on robotic applications for handling objects. [6]

The performance of industrial robots is defined on the basis of criteria such as payload, reach, dynamics and accuracy. In addition, industrial robots are differentiated in terms of

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1 For the definition of robotics, see also VDMA (n.d.), p. 8 and ISO: Robotics - Vocabulary, https://www.iso.org/obp/ui/en/#iso:std:iso:8373:ed-3:v1:en (last accessed on 16 November 2023)
2 With regard to the users, this distinction is not clear-cut, see VDMA (n.d.), p. 8
3 In the "International Organisation for Standardisation", the ISO members (national institutions) develop international standards that are later (voluntarily) adopted as national standards.
4 International umbrella organisation of national robotics associations
5 See e.g. ISO: Robotics Vocabulary, https://www.iso.org/obp/ui/en/#iso:std:iso:8373:ed-3:v1:en (last accessed on 16 November 2023), number 3.6 and 3.7
6 In 2022, handling accounted for 48% of new robotics installations worldwide, see International Federation of Robotics (IFR) (2023), p. 14

their kinematic structure, i.e. the arrangement and number of axes involved in the movement (e.g. articulated robots, delta robots, SCARA robots). [7]

Typically, industrial robots are industrial robotic systems that are customised for specific applications and essentially comprise of the following components[8] :

- Manipulator (corresponds to the actual robot or robot arm)
- End effector (corresponds to the processing tool at the end of the robot arm, e.g. a gripper)
- Robot control (function monitoring and control of the robot and the connected peripherals, communication with the user) [9]
- Sensors
- Peripherals (collective term for supplementary accessories such as tool changers, additional modules and equipment such as safety fences)

One or more robot systems with the associated machines and protected areas are often referred to as a robot cell, several robot cells as a robot line.[10]

In addition to industrial robots, professional service robots, which are primarily used for tasks related to transport and logistics as well as for cleaning and building surveillance, play an increasingly important role for industrial companies. These include mobile autonomous robots (see chapter 3.2.4), which are also important elements for the realisation of more comprehensive automation solutions (see chapter 3.2.5).

2.2 Development of the market for industrial robotics applications

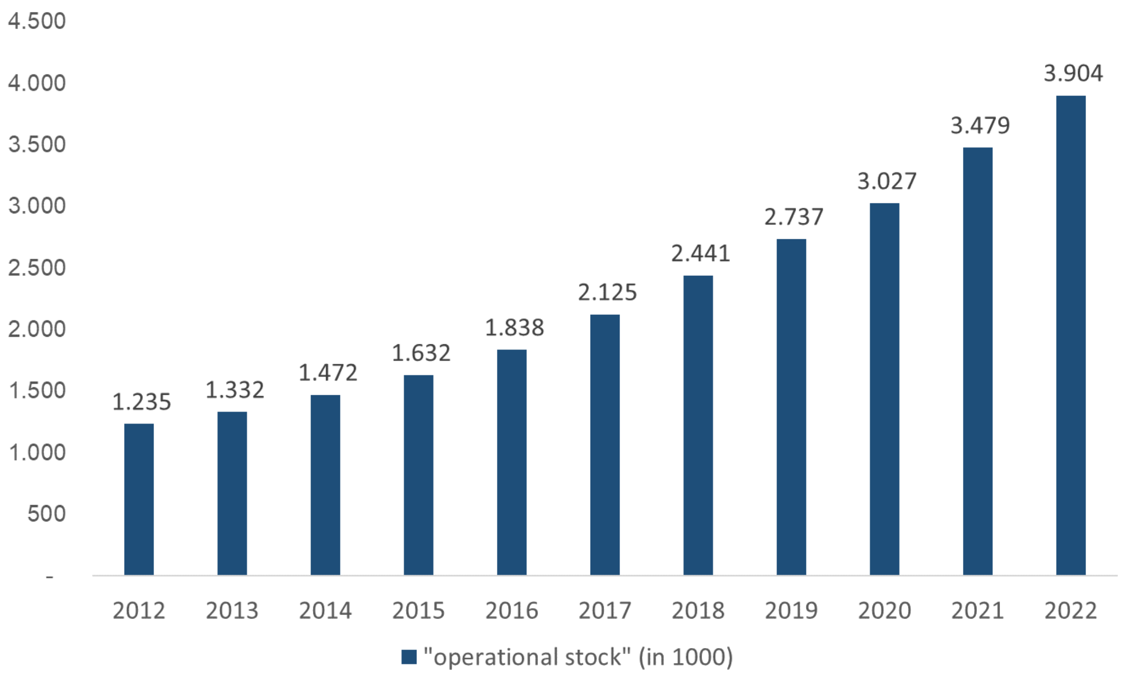
Due to the aforementioned lack of a clear definition, the market for industrial robotics applications, which is subject to the study at hand, cannot be defined statistically. However, relevant trends and developments can be identified on the basis of the IFR's[11] ongoing reporting. This is based on manufacturer surveys and uses the ISO's technical definition of terms to differentiate between industrial and service robots. [12]

According to these metrics, the global **market for industrial robots** has grown continuously since its emergence in the 1970s and has developed particularly dynamically in the 1990s.[13] Over the past ten years, the number of industrial robots in use has almost tripled (see Figure 2-1).[14] The weighted average growth rate (CAGR)

7 For more detailed information on these classifications, see IFR, https://ifr.org/industrial-robots (last accessed on 16 November 2023)
8 See e.g. o.V. (2023d)
9 See also Taschew (2022), p. 7
10 See e.g. Pilz (2018)
11 IFR: International Federation of Robotics, https://ifr.org/free-downloads/
12 Most of the facts and figures are available at International Federation of Robotics (IFR) (2023b)
13 With regard to the use of robots in Germany between 1980 and 2002, see: Armbruster, H. et al. (2006), p. 3
14 See International Federation of Robotics (IFR) (2023c) , p. 11

between 2012-2022 was 13 %.[15] A total of 553,000 industrial robots were sold worldwide in 2022. [16]

Figure 2-1: Industrial robots worldwide (2012-2022)



Source: WIK based on IFR [17]

The global growth in the use of industrial robots is strongly driven by the Chinese market.[18] In 2022, China accounted for more than half (52%) of new installations of industrial robots worldwide.[19] Germany holds a 5% share of new installations of industrial robots.[20]

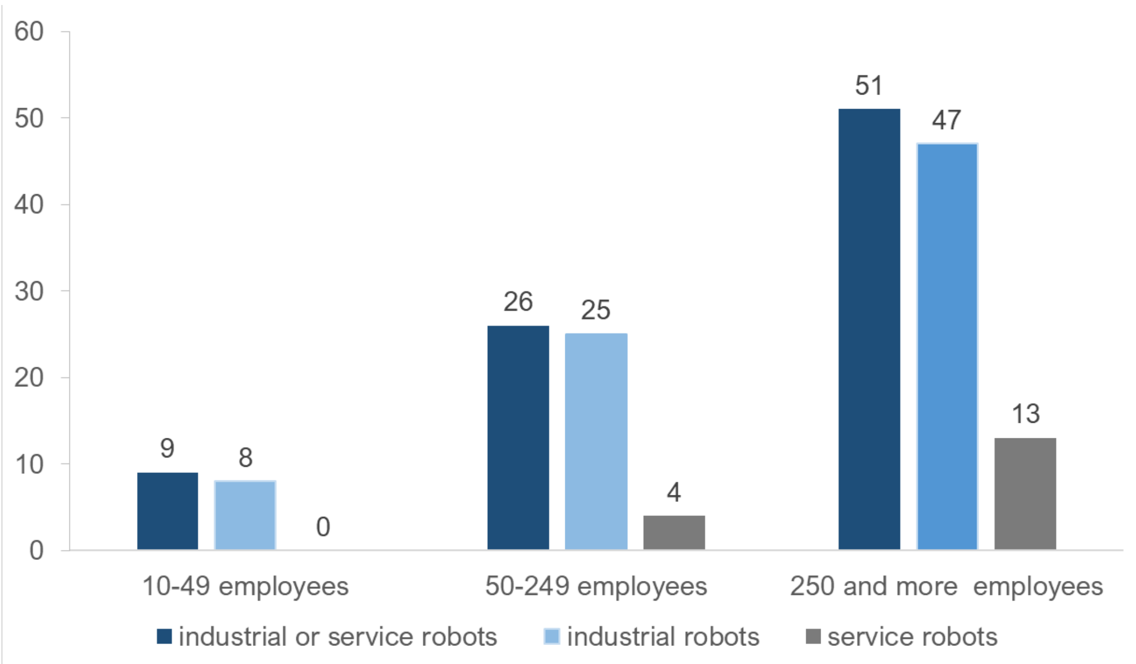
In terms of **user industries,** the electronics industry plays the most important role in industrial robot installations in the global market, followed by automotive, metal and mechanical engineering.[21] This order reflects the importance of the industries in the most important market China (and also in Japan).[22] In Germany, however, the automotive industry and metal and mechanical engineering represent the most important sectors for robotics (as in the USA).[23]

15 See International Federation of Robotics (IFR) (2023c), p. 11
16 See International Federation of Robotics (IFR) (2023c), p. 10
17 See International Federation of Robotics (IFR) (2023c), p. 10 and 11
18 For a comparison of China with the USA and Germany, see VDMA (2023), p. 23
19 See International Federation of Robotics (IFR) (2023c), p. 18
20 See International Federation of Robotics (IFR) (2023c), p. 17
21 See International Federation of Robotics (IFR) (2023c), p. 12
22 See International Federation of Robotics (IFR) (2023c), p. 20 and 22
23 See International Federation of Robotics (IFR) (2023c), p. 24 and 29

The market for **professional service robots** is very small compared to the market for industrial robotics, but is growing faster.[24] The transport and logistics sector is the most important area of application for professionally used service robots, with a share of over 50% of units sold in 2022.[25]

The use of robots in the manufacturing industry depends on the **size of the user companies** (see Figure 2-2): While around half of large industrial companies in Germany use robotics, only around a quarter of medium-sized companies (50-249 employees) do so. For industrial companies with less than 50 employees, robotics (still) plays a very minor role. Industrial robots are much more widespread than professional service robots in all size categories.

Figure 2-2: Use of industrial and service robots in German manufacturing companies (2022)



Source: Destatis[26]

Specific characteristics of the robotics offering have (so far) prevented greater utilisation by SMEs. For example, the existing robotics solutions do not yet meet the needs of

24 The IFR's market surveys provide an indication of this development, although they do not cover the entire service robotics market. The IFR reported 158,000 newly installed service robots for professional use worldwide in 2022. The year-on-year growth in professionally used service robots was 48%, compared to only 5% for industrial robots. These figures only represent a section of the market and are based on data from 239 manufacturers. See International Federation of Robotics (IFR) (2023c), p. 10 and p. 37 (data for the global stock of service robots is not publicly available)

25 See International Federation of Robotics (IFR) (2023c), p. 38

26 See Destatis (2022)

smaller industrial companies, particularly in terms of the level of investment, installation costs and ease of use.[27]

2.3 Ecosystem for industrial robotics applications

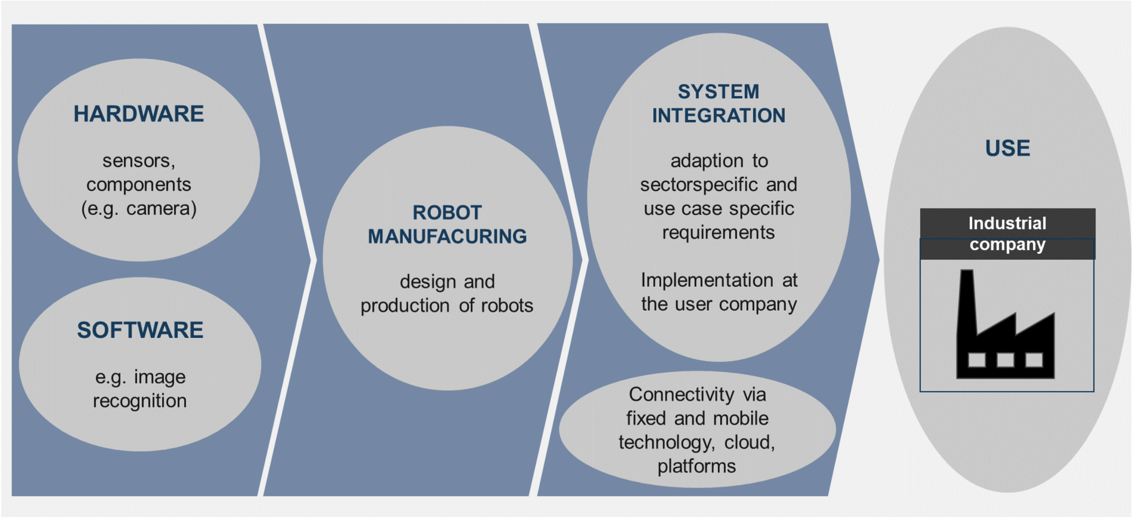
A large number of providers is involved in the development, production, marketing and installation of industrial robotics applications. Their business models vary greatly.

The development of innovative robotics applications requires **extensive research.** In Germany, robotic providers often coordinate their research activities with universities (e.g. TU Munich, RWTH Aachen, Karlsruhe Institute of Technology KIT) and non-university research institutions (e.g. Fraunhofer, DLR). Many start-ups (e.g. robominds, Agile Robots) have also emerged from the research landscape.[28] In the leading industrialised countries, state research funding plays a key role in improving the framework conditions for the national robotics industries. [29]

The most important distinguishing feature of robotics providers is their **positioning in the value chain**. This comprises of a variety of activities, ranging from the development of hardware and software components to the design, production and implementation on the sites of industrial user companies (see Figure 2-3). Furthermore, the providers of industrial robotics applications differentiate themselves in terms of the **fields of application, user industries and addressed customer groups**. There are also players that offer **robotics as part of a broad product portfolio** or develop it in addition to an existing core business (e.g. automation). The following analysis of the ecosystem focusses on the area of industrial robotics, which is more relevant for industrial user companies than the segment of service robotics. The two segments show similarities in the upstream and downstream stages of the value chain, but involve different market players in the area of robot manufacturing.

27 See also, for example, Armbruster, H. et al. (2006)
28 See for selected research projects e.g. VDI/VDE (2020), p. 39-55
29 See also IFR (2023) on government funding for robotics research in the world's leading industrialised countries: Robotics research: How Asia, Europe and America are investing - Global IFR Report 2023, https://ifr.org/downloads/press2018/DE-2023-JAN-12-IFR-PRESSEMELDUNG-RD-World_Robotics_Programme.pdf

Figure 2-3: Ecosystem of industrial robotics applications



Source: WIK

2.3.1 Global players in robot manufacturing

The majority of sales in the global robotics market are generated by **globally active robot manufacturers** that have been developing industrial robots since the 1970s. One of the pioneers was the robot manufacturer KUKA, founded in Germany (and now owned by the Chinese technology group Midea[30]), with its six-axis robot "Famulus" developed in 1971. The first important user companies of industrial robotics were car manufacturers, including Mercedes-Benz.[31] During the development phase of industrial robotics, robot manufacturers developed various proprietary approaches, e.g. their own programming languages for robot control, which still characterise the market. [32]

The leading robot manufacturers are not vertically integrated (with the exception of ABB[33]). Instead, **their focus is on** the **design and production of industrial robots** that differ in terms of their kinematics and performance characteristics such as payload and reach (see chapter 2.1). Their product portfolios have expanded considerably in recent years.

30 https://www.midea.com/de/ueber-midea (last accessed on 16/11/2023)
31 See e.g. Gasparetto, A. and Scalera, L. (2019), pp. 24-35, and, Item 24 (2022): The history of robotics simply explained, 16 February 2022, https://blog.item24.com/robotik-anwendungen/die-geschichte-der-robotik-einfach-erklaert/ (last accessed 16.11.2023)
32 For a detailed discussion of programming languages for industrial robots, see e.g. Taschew, M. (2022), p. 107 ff.
33 ABB Robotics is the only robot manufacturer to have an integrated offering and is expanding this through in-house development and acquisitions, https://new.abb.com/products/robotics/de#:~:text=ABB%20Robotics%20is%20one%20of%20our%20value%C3%B6creating%20software%20developed%20and (last accessed on 16.11.2023)

The hardware and software required for production is mainly sourced from suppliers. The downstream customisation of the robots for specific fields of application is carried out by specialists and implementation at the user company is realized by certified partners.

According to most market researchers, the robot manufacturers ABB, Kuka, Fanuc, Mitsubishi and Yaskawa **lead today's worldwide market**. However, there is no consistent data on the market share of these providers, as there are challenges such as recording robotics sales. For example, all global players generate a share of their sales in business areas outside robotics and separate robotics from these acitivities in different ways. In this context, an attribution problem also arises from the fact that robotics applications are often part of larger automation solutions.

There are major differences with regard to the geographic markets in which the global players operate. Some of the largest providers focus on the particularly relevant Asian market, while other robotics providers, however, only play an important role in Europe and the US.

Regarding the **German market**, Meyer Industry Research (2020)[34] points out that Bosch Rexroth, Jungheinrich, KUKA, Linde and SSI Schäfer are among the five robot manufacturers with the highest turnover (followed by ABB and Dürr AG). Around half of the robot manufacturers surveyed can be categorised as SMEs in terms of their turnover (less than EUR 50 million annual turnover) and number of employees (less than 250 employees).[35] These robot manufacturers, which are often owner-managed family businesses, are usually highly specialised and globally significant in their specific market segment. Around three quarters of the TOP 50 robot manufacturers in Germany specialise in the development and production of one type of robot. At the same time, robotics is usually only a sub-segment of the companies' overall product range.[36]

Moreover, there are also **global market leaders in specific sectors and fields of application.** In the field of collaborative robots (cobots), for example, the company Universal Robots, founded in Denmark in 2005, is considered the market leader (see also chapter 3.2.3).[37] German suppliers play a central role in robotics applications for automotive manufacturers, e.g. Dürr AG, which claims to be the international market leader for turnkey paint and final assembly systems as well as machine and robot technology in the automotive industry.[38]

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34 Note: the study covers manufacturers of robots, not manufacturers of components or integrators, see Meyer Industry Research (2020)
35 EU definition (deviating from e.g. IfM, which sets the threshold value for employees at 500), see Institut für Mittelstandsforschung Bonn (IfM) (2023)
36 See Meyer Industry Research (2020)
37 See Bruch, G. (2022)
38 See https://www.durr.com/de/unternehmen/die-marke-duerr (last accessed on 16/11/2023)

2.3.2 Suppliers at upstream and downstream stages of the value chain

The range of components used in robotic systems is very broad: Hardware includes, for example, sensors, grippers, end effectors, tools, mounts or cameras. Software is required for e.g. processing data/images, for remote maintenance, teaching or for user-friendly interfaces.

This segment is mainly served by **specialised providers**. The supplier structure varies greatly, however. Some areas of robotics supply (e.g. central electronic components) are dominated by large Asian manufacturers, while other components are offered by medium-sized suppliers with a global reach. The respective market positions of specialised suppliers are more difficult to assess than that of large robot manufacturers. Companies that claim to be global leaders in specialised segments of robotics include, for example, Germany-based Sick AG, which focuses on sensor-based applications for industrial applications[39] and Austrian based FerRobotics Compliant Robot Technology GmbH, which focuses on sensitive and intelligent robot elements. [40]

The customisation of robotic systems to industry- and user-specific requirements and the implementation of traditional industrial robots in companies are typically realised by partners (system integrators). In Germany, for example, 123 companies are certified as system partners of KUKA (e.g. mechanical engineering companies such as HAHN Automation).[41]

The service portfolios of system integrators vary significantly. System integrators with a broad service portfolio cover different parts of the value chain, ranging from initial demand analyses and project planning to the installation and commissioning of robotics solutions. This may also include the selection of suitable components, the coordination with hardware and software providers, the development of safety and training concepts as well as the preparation and implementation of instruction and maintenance plans.

In addition, there are a variety of specialisation options, e.g. regarding the technical implementation (which can e.g. relate to interface programming to higher-level control systems and standard interfaces and the integration into production processes). Finally, there are also fields of activity for other specialists with a focus on service and maintenance of robots (e.g. Cobolution). Their offers include various contractual agreements with regard to services and costs. [42]

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39 2022: 12,000 employees, Group sales of around EUR 2.2 billion, 50 subsidiaries and holdings world-wide, see Sick, https://www.sick.com/de/de/ueber-sick/w/about-sick/ (last accessed on 16 November 2023)

40 See https://www.ferrobotics.com/unternehmen/ (last accessed on 16/11/2023)

41 See KUKA, https://www.kuka.com/de-de/branchen/systempartner (last accessed on 16 November 2023)

42 e.g. billing on a time and material basis, continuous maintenance contracts, 24-hour support, e.g. setting up and commissioning the robot, repairs in the event of unexpected malfunctions, machine downtime and production interruptions, maintenance and spare parts service

Connectivity is essential for networked robots. This is realised in a similar way and by similar players as with other IoT applications. Robotics implementation is typically aligned with systems already in place. Against this backdrop, cloud computing providers[43] such as Amazon AWS and Microsoft Azure and network operators, offering fixed and mobile connectivity (e.g. Deutsche Telekom[44]) are of high importance, too. In general, this could also open up a new field of activity for robotics manufacturers and specialists - KUKA, for example, had been working on its own cloud solutions, but now uses the large cloud platforms Azure and AWS.[45] Other specialists can get involved to realise connectivity for robots (e.g. Device Insight).[46]

Finally, an emergence of specialised **marketplaces** in the robotics market that bring together users and manufacturers of robotics, can be observed. These players include, for example, RBTX (part of IGUS GmbH)[47], XITO and Unchained Robotics. They offer components of robotic systems that can either be purchased individually or put together as a complete solution with the help of a configurator. The offerings are geared towards more cost-effective and standardised use cases that do not require intensive consultation (e.g. RBTX offers hardware for between EUR 3,000 and EUR 30,000[48]). In some cases, turnkey solutions are offered as well (e.g. "Malocher-Bot" from Unchained Robotics, from 90,000 euros for palletising).[49]

2.3.3 Role of cooperations

Due to the complexity of the partial services to be provided for robotics applications and the diversity of market players with different focuses, **cooperations** play a significant role in the market.

With regard to the partners involved, two forms of cooperation in particular play a role.

On the one hand, smaller specialists cooperate in order to combine their respective strengths (e.g. modular robotics and AI: Robco and robominds). They also cooperate to jointly develop specific robotics applications for certain industries or fields of application (e.g. intralogistics, see Figure 2-4).

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43 For more details on cloud computing, see Godlovitch, I.; Kroon, P. (2022), p. 9 ff.
44 See the Cloud Connect service for connecting company networks with cloud providers: https://geschaeftskunden.telekom.de/magenta-business-networks/netzwerke-fuer-standorte-und-clouds/cloud-connect (last accessed on 16/11/2023)
45 For KUKA's strategy with regard to the cloud, see e.g. Dose, J. (2022)
46 e.g. for the realisation of an edge interface for connecting a KUKA robot to a Microsoft Azure Cloud at the Lego Group, https://www.kuka.com/de-de/unternehmen/presse/news/2022/03/kuka-roboter-in-die-cloud-gebracht (last accessed on 16/11/2023)
47 See more details on the business model, e.g. Koller, P. (2022)
48 See https://rbtx.com/de-DE/rbtxpert (16 November 2023)
49 See https://unchainedrobotics.de/produkte/turnkey-loesungen/unchained-robotics-malocherbot-palettieren-s and https://unchainedrobotics.de/?utm_source=google&utm_medium=cpc&utm_campaign=domainprotect&gad_source=1&gclid=EAIaIQobChMIj-_l0deVggMVnpWDBx2g0AHtEAAYASAAEgIbuPD_Bw (last accessed on 16.11.2023)

On the other hand, global players cooperate with small specialised providers. ABB, for example, is using a strategic partnership with the Swiss start-up Sevensense[50] to utilise their solutions in the fields of AI and 3D vision for its range of mobile autonomous robots.[51] In this way, globally active manufacturers are supplementing their traditional industrial robot portfolio with specialised equipment or innovative solutions. Their smaller partner companies benefit from greater visibility in the market and can demonstrate their reliability to the customer. Acquisitions of specialists also play a role for financially strong global players. One example is ABB's acquisition of ASTI Robotics to open up the segment of autonomous mobile robots.[52]

The example shown in Figure 2-4 illustrates the interaction between various specialised providers in Germany to provide an intralogistics solution that comprises a fully automated warehouse system including various types of robots and all associated software and hardware components. The implementation of the application was initiated by AI specialist robominds and realised jointly by 8 companies from Denmark and Germany.[53]

Figure 2-4: Sina: An example for a cooperative robotics solution

robotics application „fully automated vertical storage system“

Components	Stage of the Value Chain	Partner
AI skills	AI technology	robominds, München/D
Suction cup	Gripper technology	piab, Butzbach/D
Storage lifter	Storage system	EFFIMAT, Odense/DK
Cobot	Robot arm	Universal Robots, Odense/DK
autonomous mobile robot	Mobile robot	MIR, Odense/DK
roller conveyor	Robotic equipment	ROEQ, Vissenbjerg/DK
security system	Sensor manufacturing	Sick, Waldkirch/D
automation technology	System integration	ECOSPHERE, Fichtenau/D

Source: WIK based on robominds, https://www.robominds.de/loesungen/sina (graph extended by annotations)

50 Founded in 2018 as a spin-off from the Swiss Federal Institute of Technology in Zurich.
51 See e.g. ABB (2021b)
52 See ABB (2021a)
53 See the functions and components in detail at https://www.robominds.de/loesungen/sina (last accessed on 16/11/2023)

3 How is the robotics market changing due to innovative digital technologies?

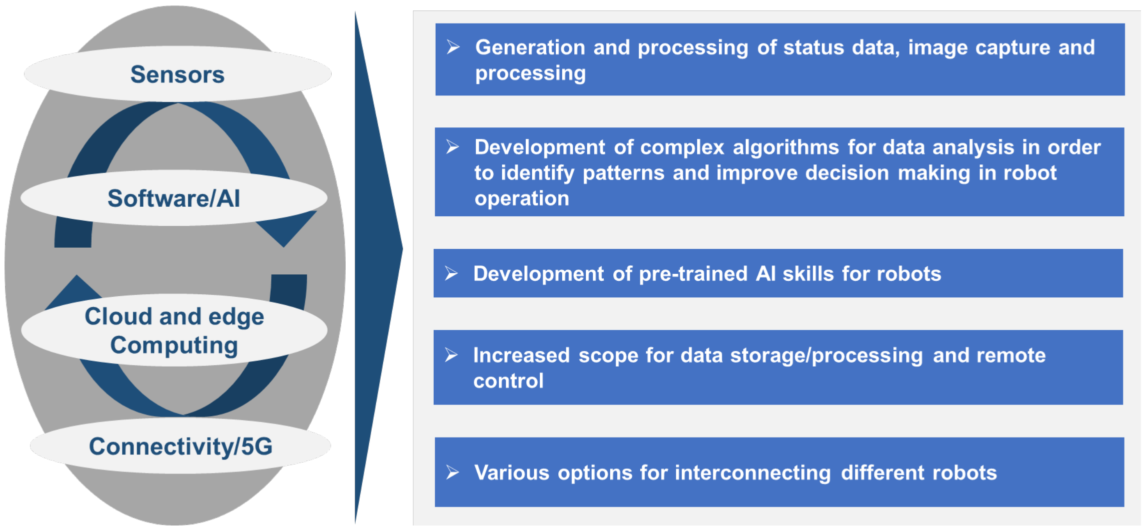
3.1 Innovative digital technologies with relevance for robotics

On a high level of abstraction, digital technologies can be summarised as all technologies that are based on (computer) hardware, software and interconnection.[54] Therefore, they represented a fundamental prerequisite for the development of traditional industrial robots that rely on robot control software.[55] Some of the concepts developed in the early stages of industrial robotics are still in use today (e.g. manufacturer-specific programming languages). In contrast, more advanced software architectures, interfaces and operating concepts are used in service robotics, which emerged much later.[56]

The changes in industrial robotics enabled by digital technologies are taking place gradually and, unlike in many other markets, have not yet led to disruptive developments that render existing business models obsolete. Innovations in the field of digital technologies act as enablers for the development of significantly expanded and even completely new robotics applications. They offer opportunities in the fields of data acquisition (using sensors), processing (using software/AI), storage (e.g. via cloud/edge) and transmission (e.g. 5G). The benefits for robotics arise less from the performance of individual digital technologies than from their interaction. For example, processing a high volume of data for AI applications also requires sufficient storage options. The feasibility of mobile/autonomous robotics applications (see chapter 3.2.4), which depend on secure real-time navigation, requires not only comprehensive sensor technology and AI, but also cloud solutions and WLAN as well as increasingly powerful mobile communications infrastructure.[57]

54 See Federal Ministry for Economic Affairs and Climate Protection (BMWK) (2022), p. 4
55 The beginning of the commercial introduction of industrial robotics is often dated to 1961, when the US robot supplier Unimation introduced the Unimate industrial robot at General Motors for the removal and separation of injection moulded parts, see e.g. Marsh, Allsion (2022)
56 See Taschew, M. (2022), p. 10
57 See in detail International Federation of Robotics (IFR) (2021)

Figure 3-1: How can digital technologies enhance robotics applications?



* Digital technologies = technologies based on (computer) hardware, software and networking

Source: WIK

Sensors are technical components or hardware modules that record a variety of different variables and convert them into electrical signals that can be further processed. The range of measurable indicators is very broad and includes, for example, physical properties such as temperature, humidity, pressure, brightness or acceleration. The data generated via sensors can be used, for example, to monitor conditions (e.g. detecting temperature fluctuations) or allow the detection of human presence (e.g. using motion or heat sensors). Sensor technology is also used to take images with cameras. Whereas in the past only simple sensors (e.g. temperature sensors) were available, today innovative measurement concepts and integrated sensor systems are being developed in order to meet the specific requirements of their respective field of application.[58] Software, electronics and sensor development are increasingly interconnected with each other.[59] Sensors are central to robotics, as they generate the basic data for further processing by means of appropriate software/AI solutions. [60]

Software has characterised industrial robotics from its beginning, as it enables robots to be controlled. Since then, it has developed continuously. Robots require a programme to perform a task, which must specify the sequences (e.g. start, intermediate and target points as well as the movement to be executed at each stage). Programming in robotics

58 See e.g. https://www.ims.fraunhofer.de/de/Kernkompetenz/Smart-Sensor-Systems/Integrated-Sensor-Systems.html (last accessed on 16/11/2023)

59 See Werthschützky, R. (2022) for detailed information on development trends in sensors and relevant technologies

60 For an overview of sensor modules used in robotics, see e.g. also https://www.roboter-bausatz.de/c/diy-elektronik/erweiterungsmodule/sensoren/ or https://www.te.com/deu-de/whitepapers/sensors/the-role-of-sensors-in-the-evolution-of-robotics.html (last accessed on 16 November 2023) and for a complete overview of around 100 parameters that are measured using sensors on the market Werthschützky, R. (2022), p. 12

is based on various programming languages, some of which are manufacturer-specific.[61] Innovative robotics applications can only be realised with the appropriate software, e.g. for the further processing and preparation of sensor data or for image processing.

Developments in the field of **artificial intelligence (AI)**[62] are particularly important, as they provide complex algorithms to analyse large amounts of data with regard to patterns in order to derive decisions. They enable the robot to be used for more complex tasks that require a high degree of flexibility (see chapter 3.2.2).[63] AI gives the robot a "brain" that can interpret data in real time and react with an appropriate action immediately. This represents a key advance for innovative robotics applications: robots with AI skills do not require a learning process for each individual object or environment, but are already "pre-trained" to handle a wide range of objects or navigate in unknown environments. This shift from predefined executions for a very limited activity to independent actions in changing environments contributes to a significant expansion of potential applications for robots.

Processing large volumes of data requires powerful computing and transmission capacities. These can be in particular provided by **edge and cloud technologies**. The use of **cloud platforms**[64] for robotics applications enables software updates and upgrades, remote access for control, programming and simulations with "digital twins" as well as the continuous measurement and evaluation of robot data. In the case of moving transport robots, for example, the complete relocation of the control technology to the cloud enables the execution of a wide range of tasks as well as improved cooperation and coordination between different robots. High computing capacities are often only required temporarily (e.g. for training algorithms) and can be provided flexibly via the cloud.[65] **Edge gateways** can also be deployed between the robot and the cloud in order to collect, consolidate and encrypt data at the local edge level. They also serve to supplement missing cloud-compatible communication protocols of the connected robots and to relieve the cloud.[66] Edge and cloud technologies can therefore be seen together as drivers for increasing networking and play a key role in the realisation of the smart factory (see chapter 3.2.5). [67]

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61 e.g. Karel (FANUC), KRL (Kuka), Inform (Yaskawa), RAPID (ABB), see above (2021)
62 See in detail on AI, e.g. Fraunhofer IKS (2023)
63 "Conventional industrial robots are just machines that move from one point to another, as they have to be taught in point by point. This makes the processes rigid and inflexible. The use of artificial intelligence enables robots to use eyes (3D cameras) to see things. It provides local intelligence to create its own motion plans so that objects can be handled without exact point-to-point programming. With the option of additional force sensors, the robotic arm can also be equipped with "feel" to recognise the exact position of objects." Robominds, https://www.robominds.de/robominds/robominds-ki (last accessed on 16/11/2023)
64 See in detail on cloud platforms Godlovitch, I.; Kroon, P. (2022)
65 See https://news.microsoft.com/de-de/cloud-fuer-ki-einsatz-und-roboter/ (last accessed on 16/11/2023)
66 See in detail Groshev, M. et al. (2023), pp. 166-174
67 For practical implementation, see also KUKA: Mit KUKA zur Digital Factory, https://www.kuka.com/de-de/future-production/industrie-4-0/digital-factory (last accessed on 16 November 2023) and on the theoretical background Groshev, M. et al. (2023), pp. 166-174

Connectivity technologies are required to connect the robot to the cloud. In addition to fixed network technologies (e.g. Industrial Ethernet), various radio technologies are important here, which cover a wide range of possibilities in the licensed or licence-free spectrum. 5G technology enables the development of robotics applications that require low latency and high reliability (e.g. mobile autonomous robots, see chapter 3.2.4).

3.2 Digital technologies as enablers for new applications and further developments in the industrial robotics market

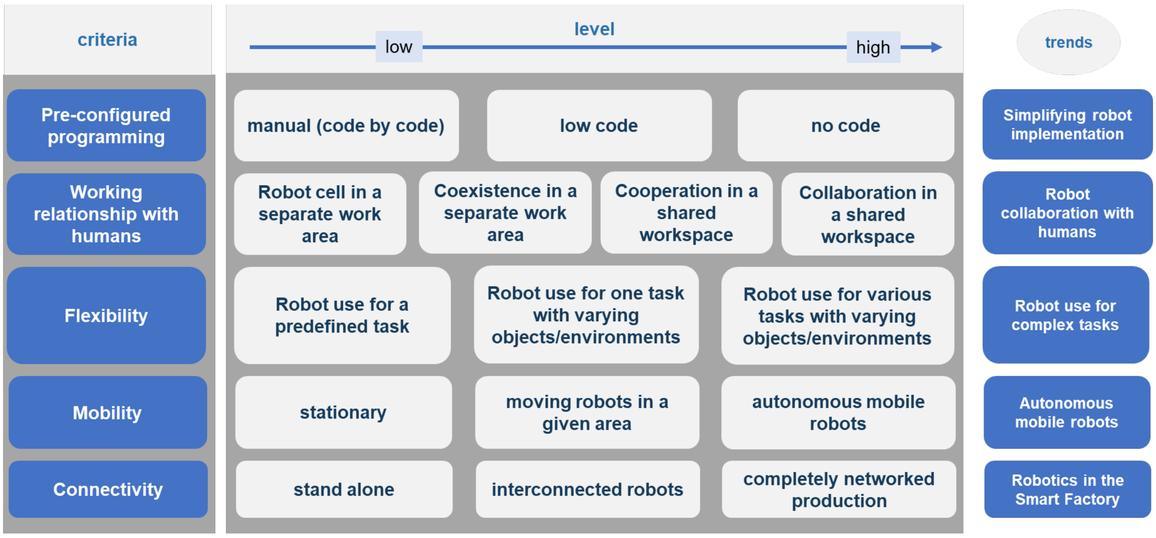
Decades of growth in the industrial robotics market have so far taken place in the segment of large user companies and focussed heavily on the automotive industry (manufacturers and suppliers). As early as 20 years ago, it was recognised that smaller, easier to handle, quick to install and inexpensive industrial robots for SMEs should be developed, as the existing range of robotics did not meet the needs of SMEs from a technical and economic point of view.[68] However, it is only in the last 10-15 years that the market has started to move, mainly due to the activities of start-ups that have emerged from research institutions. These new providers consistently make use of the opportunities of innovative digital technologies for the development of new and the improvement of existing robotics applications.

Innovative digital technologies offer potentials for the development of robotics applications in many respects. In contrast to other markets, however, they haven't yet lead to disruptions as changes are taking place gradually and are characterised by various intermediate stages (see Figure 3-2) .

In particular, robotics applications are continuously being simplified and become more flexible. Moreover, innovative digital technologies provide more options for connected robots and mobile use and enable a closer collaboration with humans. In their most advanced stage, these digitalisation-related design options for robotics applications lead to the simplification of robot implementation, robot collaboration with humans, the use of robots for complex tasks, mobile autonomous robots and robotics in the smart factory.

68 The SMErobot research project, for example, was developed against this background, see Armbruster, H. et al. (2006), p. 12

Figure 3-2: How are digital technologies changing the possibilities for the development of robotics applications?



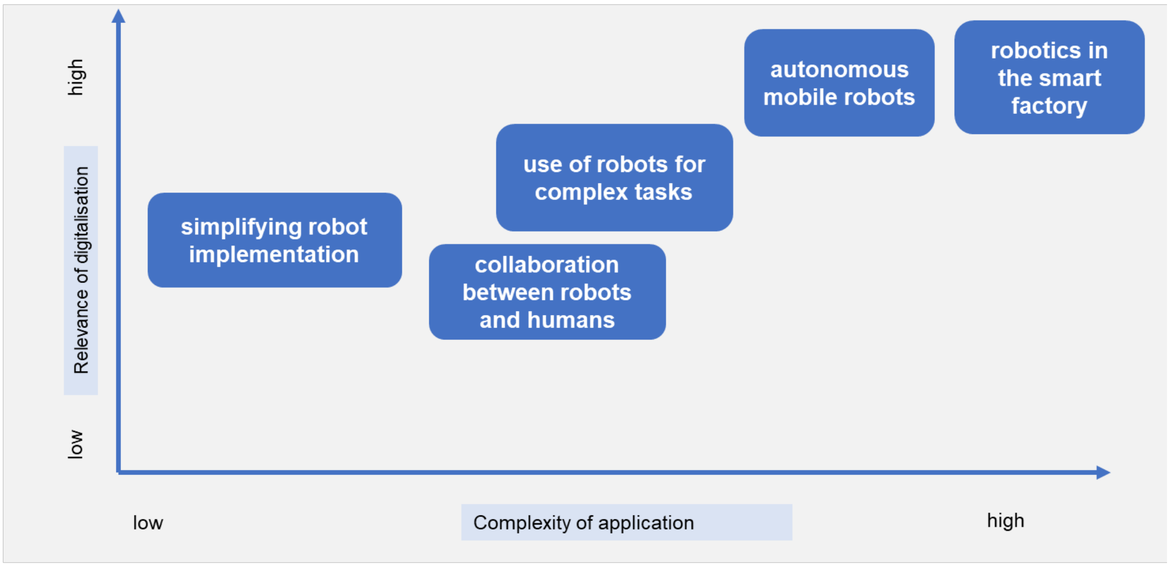
Source: WIK

The complexity of the robotics applications that can be realised varies greatly (see Figure 3-3). The more demanding the robotics applications are in terms of development and implementation, the less they have been realised in practice to date. While simplified robot implementation is already considered standard for new developments today, robotics in the smart factory has so far only been implemented step by step by a few pioneering companies.

The relevance of digitalisation for these market trends varies. For example, human-robot collaboration depends not only on digital technologies, but also on safety concepts and structural aspects (e.g. round contours, lightweight material).[69] Digital technologies are also a key driver for simplified robot implementation, but other aspects (e.g. employee training, standardisation) play a role, too. The smart factory, on the other hand, is a market trend that could not develop at all without digital technologies.

69 See e.g. Umbreit, M. (2020)

Figure 3-3: Digitalisation-driven market trends in industrial robotics applications



- ***Relevance of digitalisation:*** *To what extent do the feasible applications depend on digitalisation?*
- ***Complexity of the application:*** *How demanding is the conception and implementation of the feasible robotics applications?*

Source: WIK

In the following chapters, the five market trends are analysed with regard to the status quo and market penetration, the contribution of digital technologies and their potential impact on the value chain.

The market trends cannot be clearly distinguished from each other. For example, approaches to simplify robot implementation play a role for other market trends as well. The smart factory combines all of the aforementioned development trends .

3.2.1 Simplification of robot implementation

3.2.1.1 Status Quo

The implementation of traditional industrial robotics applications in industrial companies requires specific expertise and is typically carried out by system integrators.

As part of the implementation, tests and adjustments to the robots are required before they can finally be put into operation. Some implementation efforts relate to the programming required to commission the robot.[70] This can only be carried out by

70 For detailed information on the programming effort in the various phases from application development to commissioning (using BMW as an example), see Taschew, M. (2022), p. 47

specialists, who are familiar with the programming language of the respective robot manufacturer.[71]

Particular challenges can arise when new robots have to be integrated into existing production environments ("brownfield"). Proprietary/manufacturer-specific systems may cause increased integration costs, which are particularly difficult to assess in advance. Manufacturer-specific features can affect mechanical and electrical aspects as well as software and operating interfaces.[72] This can be caused by proprietary systems with manufacturer-specific robot programming languages[73] or differences in the operating concepts that require additional employee training. Although they are no invincible barriers, they are cost-intensive and can result in dependence on systems already in use[74] and represent empirically proven obstacles on the user side.[75]

Overall, the cost of robot implementation is one of the main reasons for the low demand for robotics in small and medium-sized industrial companies.[76]

3.2.1.2 Contribution of innovative digital technologies

Innovations in the field of software development and programming simplify the implementation of robotic solutions. Examples include **reduced programming efforts** during the implementation processes and the possibility to **simulate the initial operation** by means of digital twins of the robot:

- In the software sector, tools are being developed that can greatly reduce the amount of manual programming required. This development is not limited to robotics, but is gaining importance for various fields of application.[77] Most relevant here is the **pre-configuration of relevant steps or functions** that can be used by both professional developers and specialist users without specific programming knowledge. Programming in the form of writing code line by line is no longer or hardly ever necessary, as the codes are summarised in reusable components. These components are provided on so-called "**low-code/no-code platforms**".[78] They usually also offer visual user interfaces that allow individual application components to be arranged using drag & drop. Both manufacturer-

71 See also, for example, Strehlitz, M. (2022)
72 See in detail on manufacturer dependency in industrial robotics (with particular reference to the automotive industry) Taschew, M. (2022), p. 10 f.
73 e.g. Fanuc: Karel, Kuka:KRL, Yaskawa: Inform, ABB: RAPID, see above (2021)
74 See e.g. Taschew, M. (2022)
75 See, for example, a survey by McKinsey (2023)
76 See e.g. Armbruster, H. et al. (2006)
77 These developments are not only relevant in robotics, but in many application areas, e.g. enterprise resource planning (ERP), customer relationship management (CRM): For general information on the relevance of low-code programming in German companies, see techconsult (2021)
78 There is sometimes talk of no-code programming, whereby no clear boundary can be drawn between no-code and low-code. In addition, a minimum amount of code typically remains in the application development and deployment process (e.g. code for integration into other applications or for user-specific customisation), see e.g. https://www.computerweekly.com/de/definition/Low-Code-und-No-Code-Entwicklungsumgebung (last accessed on 16/11/2023)

specific solutions and independent software offerings are widespread on the market.[79] No-code development can essentially be seen as an extreme form that preconfigures all codes and often works with particularly complex user interfaces. In the field of robotics, for example, there is the no-code approach of the "Tracepen" developed by Wandelbots. Tracepen is a user-guided sensor-equipped pen that records the desired movements of the robot as a path, which can then be fine-tuned via an app and finally translated into the codes of the robot's respective programming language.[80]

- Parts of the programming process can also be carried through **cloud-based simulations with digital twins**, which accurately reflect the real robot configuration, their movements, paths and activities. This allows tests to be carried out in a "virtual initial operation" and to make adjustments before the offical launch. This shortens the actual processes and prevents downtimes caused by time-consuming troubleshooting during ongoing robot operations. It is also possible to train employees in advance on the digital twin of the real robot. [81]

AR/VR technologies for remote commissioning and employee training can also facilitate the implementation of robotics applications in industrial companies.[82]

In addition to innovative digital technologies, other aspects play a role in simplifying the implementation of robotics, too. These include, for example, solutions to improve interoperability through initiatives such as umati.[83] Here, the OPC-UA data exchange standard for industrial communication is being customised for specific industries, including robotics.[84] The introduction of open robotics operating systems (e.g. ROS 2.0) can also help to reduce the efforts involved in implementing robotics. [85]

Some organisational challenges, such as the development of safety concepts, risk assessments and certifications prior to actual commissioning, remain. However, they are changing in part as a result of digitalisation-based market trends (e.g. collaborative robots).[86] Developments in the area of framework conditions (e.g. further development of standards and norms) and publicly funded support measures (e.g. transfer of expertise,

79 See production.de (2023)
80 See https://dialog.vde.com/de/vde-dialog-ausgaben/2022-01-sustainability/no-code (last accessed on 13/11/2023)
81 For the possibilities and effects of robotics simulation via the cloud, see e.g. Barga, R. (2020)
82 See e.g. https://www.it-production.com/automation-und-robotik/extended-reality-in-der-produktion/ (last accessed on 13/12/2023)
83 See also the activities of the UMATI initiative, https://umati.org/ (last accessed on 16 November 2023) on the dissemination and implementation of industry adaptations using Companion Specifications of the UPCA-OA and on aspects of interoperability in mechanical engineering in the broader sense VDMA (2021)
84 See OPC 40010 UA for Robotics, https://umati.org/industries_robotics/ (last accessed on 16 November 2023)
85 See in detail Taschew, M. (2022), p. 19 ff.
86 See also https://dialog.vde.com/de/vde-dialog-ausgaben/2022-01-sustainability/no-code (last accessed on 16/11/2023)

implementation of pilot projects, development of demonstrators in SME Digital Centres[87]) are particularly relevant to lower the barriers to implementation in SMEs.

3.2.1.3 Effects on the value chain

The players in the robotics market are developing a wide range of new applications that enable increasingly simple robot implementation and can also reduce the amount of customisation required during operation.[88] For example, the robotics solutions presented at automatica 2023 showed that visual user interfaces are already standard in new robotics applications. Cloud based simulation options also gain importance. In the future, AI and machine learning will enable robots to recognise what they should do themselves.[89] The vision for the future is the "democratisation of robotics"[90] - a market trend that is also documented in the IFR's current market statistics.[91]

Efforts to simplify the implementation of robotics are aimed at overcoming barriers to utilisation and lowering the entry barriers for smaller new users in particular. This creates additional market potential for robotics applications in industry, to the benefit of all providers in the robotics ecosystem.

Modular robotics is an example of a new business model that combines different approaches for simplified implementation. At its core, it is about customising the robot according to the modular principle. One of the companies offering modular robotics is the start-up Robco (see Figure 3-4).

87 See, for example, Mittelstand-Digital Zentrum Chemnitz: Unterstützung bei der Inbetriebnahme einer neuen Produktionshalle, https://digitalzentrum-chemnitz.de/projekte/intralogistik-entwickeln/ (last accessed on 16.11.2023) as a basic publication also Mittelstand-Digital Zentrum Handwerk (2023) and further explanations and videos on the potential of robotics in the skilled trades at https://handwerkdigital.de/Robotik (last accessed on 16.11.2023)

88 See for various products and solutions in "Easy to use robotics" e.g. https://robotik-produktion.de/kategorie/grosser-tedo-herbst-der-innovationen/ (last accessed on 13/12/2023)

89 See also above (2021)

90 See Strehlitz, M. (2022)

91 See International Federation of Robotics (IFR) (2023), p. 35

Figure 3-4: Supplier example for modular robotics: Robco GmbH

Modular Industrial Robotics: Robco GmbH	
Who is the provider?	Robco emerged from the Technical University of Munich and has been commercialising its business model since 2013.
What is its position in the robotics value chain?	Robco is vertically integrated and manufactures the robots in Munich.
	Solutions for certain standard use cases (e.g. palletising, laser engraving, milling and turning) are pre-configured and offered from a single source; for other use cases there are cooperations with system integrators.
	Robco works together with many players in the robotics market, including providers of end effectors (e.g. Schunk, Schmalz) and safety solutions (e.g. Sick).
What is the offer?	The focus is on the modularisation of the offering: the robotics solution can be configured from various hardware modules.
	Sensors are integrated into the individual modules. Robco's software automatically recognises the connected modules, their configuration and current application. The robot can be further configured as a digital twin via the cloud (Amazon Web Services AWS).
	The configuration is low-code/no-code: Work steps can be learnt simply by the user manually guiding the robot to the desired points and saving them on the panel supplied.
Who are the users?	In particular, small and medium-sized industrial companies that automate robots for several tasks within a production system. The current areas of application are primarily machine loading, pick & place, palletising and dispensing.
What is the benefit?	The completely digital implementation enables rapid commissioning on site at the user company. Robco states that this can be realised within one day. Customisation and adaptability to different production requirements are further advantages of modular robotics. In addition, the solutions tend to be more cost-effective, as only the required modules need to be purchased.

Sources: Robco, https://www.robco.de/losungen/overview (last accessed on 16/11/2023), white paper "5 advantages of modular robots"

Cloud providers benefit from the increasing role of cloud-based applications for simplified robotics implementation. As in other parts of the economy, the major cloud providers Amazon (AWS) and Microsoft (Azure) are likely to play a key role in the robotics market, too. While Azure has its strength in the enterprise sector, AWS stands out with its wider range of IoT services and industry-specific offerings.[92]

Both companies offer robotics developers (and also user companies) additional services that are very closely linked to the cloud.

- **For example, Microsoft Azure** developed the AI-based services Azure Cognitive Services and Azure Machine Learning, which are also relevant for the implementation of robotics.[93] Further training and simulation technologies are being researched as

92 For a detailed comparison of the providers AWS, Google and Microsoft Azure, see also Bremmer, M. (2022)

93 https://azure.microsoft.com/de-de/products/ai-services?activetab=pivot:azureopenaiservicetab (last accessed on 16/11/2023)

part of R&D at the Autonomous Systems and Robotics Group.[94] This includes, for example, investigating the potential use of ChatGPT for robotics applications, in particular through the use of voice control instead of coding.[95]

- **Amazon Web Services (AWS)** developed AWS RoboMaker[96], a cloud-based service that enables robotics developers to run, scale and automate simulations and use it to train machine learning models. Amazon is also a robotics user itself and has been using robotics to optimise all areas of logistics since 2012: In early 2012, Amazon bought Kiva, a company which produces mobile robots. Current fields of application for robotics at Amazon range from autonomous mobile robots and AI-based scanning solutions for automatic parcel identification to comprehensive parcel sorting solutions. [97]

Alphabet is positioned differently. With Google Cloud as a global cloud provider, the company is also important for the robotics market, but is likely to play a smaller role than AWS and Microsoft Azure in the overall cloud market for robotics applications. However, Alphabet has already attracted attention in the past with ambitious plans in relation to robotics and has even invested in the production of its own robots (acquisition of Boston Dynamics in 2013).[98] However, this plan to move into other robotics value creation stages has since been abandoned.[99] Alphabet's robotics activities are currently bundled in the subsidiary Intrinsic, which was founded in mid-2021 with a focus on industrial robotics. In December 2022, Google acquired the robot operating system ROS from Open Source Robotics Corporation.[100] Furthermore, software tools for fast and affordable robotics development (e.g. Flowstate) are offered.[101]

Intrinsic's vision is to "democratise robotics".[102] Another relevant activity comes from the AI department Google Deepmind, which has existed since 2010.[103] Here, for example, machine learning approaches for robotics ("Robotic Transformer 2 (RT-2)") have been developed.[104] Future-oriented activities are being pursued as part of the robotics topic at Google Research, e.g. a visual language model for robot control (PaLM-E), which was developed in cooperation with the TU Berlin.[105]

Cloud providers undoubtedly play an important role for the robotics market, as they are used by robotics providers to develop new business models. The extent to which the

94 https://www.microsoft.com/en-us/research/group/autonomous-systems-group-robotics/ (last accessed on 16/11/2023)
95 See Vemprala, S. et al (2023)
96 https://aws.amazon.com/de/robomaker/ (last accessed on 16/11/2023)
97 See Amazon (2022)
98 See e.g. Lowensohn, J. (2013)
99 See Tobe, F. (2017)
100 See Crowe, S. (2022)
101 See https://intrinsic.ai/flowstate/ (last accessed on 16/11/2023)
102 See https://intrinsic.ai/ (last accessed on 16/11/2023)
103 See https://deepmind.google/ (last accessed on 16/11/2023)
104 See Chebotar, Y.; Yu, T. (2023)
105 See Szöke, D. (2023)

cloud providers themselves will penetrate further into the robotics value chain is still difficult to judge today.

Another group of providers likely to be affected by the trend towards simplified robot implementation are the traditional system integrators. Their business model, which specialises in the complex implementation process at the user company, must be adapted to a changing environment. However, there will be still a need for further support and guidance in the different steps of robot implementation processes.

3.2.2 Robots for complex tasks

3.2.2.1 Status Quo

Traditional industrial robots are specifically configured and programmed for particular applications. They require a fixed flow chart in the form of a programme that gives them precise instructions in their respective programming language with regard to the points to be controlled.[106] Software solutions, which are widespread today, are only capable to a limited extent to recognize and process changing objects and environments, however.

Due to their technical design and the corresponding investment requirements, industrial robots are primarily economically viable for large-scale production. Conventional industrial robots are not suitable for production with many variants and high demands on the flexibility of use, which is particularly prevalent in medium-sized industrial companies.

3.2.2.2 Contribution of innovative digital technologies

The ability of a robotic system to perform complex tasks requires, in particular, continuously improved image recognition systems using associated software solutions and innovative gripping techniques. Further developments in **AI** that can adapt motion sequences in real time to current environmental conditions and varying object properties such as colour, surface or shape play a key role in expanding the possible use cases of robotic applications.

There are numerous applications and fields of use in robotics that benefit from these characteristics. These include, for example, applications in the important field of handling. In the "bin picking" sorting application, in which the robot removes objects from a bin and places them in a different location for the next production step, there are restrictions when handling different types of objects without AI. For example, the robot cannot remove all objects and manual intervention is required after some time in order to avoid production

106 Robot programming must take into account, for example, degrees of freedom, positioning accuracy, repeat accuracy, payload, path fidelity and process speed, see above (2021) downtimes.[107] AI technologies are used to optimise the complex interaction between image recognition systems, software, gripping technology and the robot systems in order to achieve the most complete emptying of the container possible.[108]

In addition, the performance of robotic systems for handling complex tasks can also be increased by **edge and cloud technologies.** They offer greater flexibility for robotics solutions because they do not require extensive local computer capacities and also provide options for remote cloud-based control of production processes.[109] For example, software updates can be realised during operation, which increases the adaptability of robotic applications.

3.2.2.3 Effects on the value chain

By enabling robots to perform complex tasks, applications can be realised that were previously not feasible due to technical restrictions. In particular, they can be targeted to new user groups for whom robotics was previously not feasible, e.g. medium-sized industrial companies with high product diversity. This creates additional market potential for industrial robotics applicationsto the benefit of all providers engaged in the robotics ecosystem. Due to the great importance of AI solutions, there are particularly good opportunities for AI specialists.

The development of AI solutions is being driven forward intensively in research projects at universities and non-university research institutions, from which numerous start-ups have emerged. One example of a German start-up that utilises the possibilities of AI for robotics is robominds (see Figure 3-5).

107 See e.g. .B. on the previous solutions and their limitations in the application "Griff-in-die-Kiste: Mossmann, M. (2022)
108 See Fraunhofer IPA (2022)
109 See e.g. https://www.ericsson.com/en/cases/2016/5gtuscany/transforming-industry-with-5g-cloud-robotics (last accessed on 16/11/2023)

Figure 3-5: Provider example for AI-based solutions: robominds GmbH

AI-based solutions: robominds GmbH	
Who is the provider?	robominds is a company founded in 2016 that emerged from the Technical University of Munich. robominds is focused on AI-based solutions for robotics.
What is its position in the robotics value chain?	robominds' offering is based on an industrial computer (robobrain), which acts as a control platform for other robotic components and AI skills and has its own open operating system (NEUROS 2.0).
	For the development of complete solutions, robominds works together with robot manufacturers (e.g. FANUC, Universal Robots, MIR) and with other relevant players for the provision of industry solutions (e.g. Hörmann Logistik, Effimat).
What is the offer?	The product portfolio is based on the development of AI skills (e.g. "smart item detection skill") that are pre-trained, e.g. for the generic detection and handling of objects that differ in terms of size and form. AI skills have to be downloaded to the robobrain platform. robominds also offers solutions for hand-eye-coordination.
Who are the users?	robominds' current focus is on solutions for warehouse logistics and laboratories.
What is the benefit?	The range of uses of existing robotics applications, such as handling, is optimised. For example, an increase in product availability can be achieved in warehouse logistics.

Source: WIK based on public information from robominds GmbH

3.2.3 Collaborations between robots and humans

3.2.3.1 Status Quo

Traditional industrial robots are characterised by their high performance. They can work quickly, precisely and with high repetition rates, particularly in highly standardised processes. The fast movements and high force of industrial robots pose a risk to people in their immediate surroundings. Therefore, following a comprehensive risk assessment, traditional industrial robots must be equipped with adequate safety measures, which are regulated in DIN EN ISO[110] 10218 01 and 02 and are based on the EC Machinery Directive 2006/42/EC.[111] In particular, these regulations deal with protective equipment, which restricts the access of people to danger zones and can be, e.g., implemented in the form of fences, light curtains or laser scanners.

110 "German Industrial Standard and European Standard for International Organisation for Standardisation" is a certification for a product or process that complies with internationally recognised standards and regulations

111 The draft standard is currently being revised - including with regard to collaborative robots, see the various documents on standardisation DIN, https://www.din.de/de/ueber-normen-und-standards (last accessed on 16/11/2023). The complete texts of DIN EN ISO 10218 can be obtained for a fee from Beuth Verlag.

The challenge in a very strong separation of labour between humans and robots is to combine the performance characteristics of robots with the abilities of humans for intelligent work and skilful coordination (e.g. dexterity, hand-eye coordination). This results in untapped potential in industry, especially in complex assembly and handling processes, regardless of the size of the user.[112]

Various approaches have been developed for greater collaboration between humans and robots, which differ in terms of the intensity of the collaboration. In addition to the degree of spatial separation (shared or separate workspace), other aspects such as the form and type of human involvement in the robot's work also play a role.[113]

Since 2016, there have been specific protective measures for human-robot collaboration that are regulated in ISO/TS 15066.[114] On this basis, there are essentially two options that allow a safe collaboration between man and machine. Firstly, it is possible to use speed and distance monitoring to ensure that physical contact between humans and robots is excluded by switching off the robot if the distance to the human falls below a minimum level. On the other hand, power and force limits can be set from the outset to ensure safe contacts between humans and robots.[115]

The increasing collaboration between humans and robots has been established in various forms in the industrial robotics market for around 15 years and forms a small but rapidly growing market segment.[116] The extended application possibilities of robots are particularly useful for small and medium-sized companies, craft businesses and production facilities with limited space. Other advantages of collaborative robotics solutions include improved ergonomics for production employees and flexibility in terms of location.[117]

Collaborative robots are launched both in the form of targeted new developments ("cobots") and as an extension of traditional industrial robots. As soon as the new forms have to fulfil the safety requirements of the ISO standard, they are statistically recorded as "cobots" by the IFR based on manufacturer reports. According to the IFR, the share of cobots in annual new installations in global industrial robotics was 3% in 2017 and has risen at a CAGR of 38% (2017-2022) to a share of 10% in 2022.[118]

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112 See also Surdilovic, D. et al. (2018)
113 See, for example, Onasch, L. et al. (2016)
114 Adopted in 2016 and last revised in 2022, See ISO: ISTO/TS 15066, https://www.iso.org/standard/62996.html (last accessed on 16 November 2023) and Lazarte, M. (2016)
115 See also Fraunhofer IFF (2018)
116 See also European Parliamentary Research Service (2023)
117 See e.g. Fraunhofer IGCV (2022), p. 6
118 Data for 2022 is not yet available in the IFR's current 2023 market study, see International Federation of Robotics (IFR) (2023), p. 15

3.2.3.2 Contribution of innovative digital technologies

Sensors, software and AI play crucial roles in fulfilling the conditions under which robots can work more closely with humans.

Sensors (e.g. force and pressure measurement) and corresponding software-based solutions (for processing the measured variables for control and planning purposes) are prerequisites for speed and distance monitoring as well as for power and force limitation.[119] Further developments in the field of AI methods of machine learning improve the possibilities of collaboration (e.g. through intelligent real-time reactions to human activities) and proactive and efficient assistance (e.g. in various assembly phases).[120] In particular, intelligent image processing systems are used to adapt robot activities to the positions and movements of humans captured by cameras .[121] Voice control options can also be useful for human-robot collaboration in certain applications.

As already mentioned, in addition to digital technologies, human-robot collaboration also requires structural innovations (in particular lightweight robotics using light construction materials and design changes such as rounded contours) as well as safety concepts (e.g.in the form of training).

3.2.3.3 Impact on the robotics value chain

The trend towards greater collaboration is already being taken up by numerous robotics providers with very different company backgrounds and business models, from start-ups to global players.

KUKA's first steps towards collaborative robots were based on research into lightweight robotics at the DLR Institute of Robotics and Mechatronics. This institute had been conducting research into lightweight robotics since the 1990s, presenting its first robot (LBR I) in 1995 and subsequently developing it further until it was licensed to KUKA in 2004.[122] KUKA, the leading German robot manufacturer at the time, continued to develop the LBR until it was launched on the market, particularly with car manufacturers.[123] However, KUKA did not succeed in utilising this pioneering position for broader market penetration. The cobots offered by KUKA were too strongly tailored to major customers and did not meet the needs of SMEs in terms of cost and applicability.[124]

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119 See also Fraunhofer IFF (2018)
120 See also IFR, https://ifr.org/industrial-robots (last accessed on 16/11/2023)
121 See with regard to research on the AI-based cobot Fraunhofer IOSB, https://www.iosb.fraunhofer.de/de/projekte-produkte/cobot.html (last accessed on 16 November 2023) and as a provider of an AI cobot Techman Robot, https://www.tm-robot.com/en/ (last accessed on 16 November 2023)
122 See DLR: History of the LBR, https://www.dlr.de/rm/desktopdefault.aspx/tabid-12464/21732_read-44586/ (last accessed on 16 November 2023)
123 See KUKA: Cobots: collaborative robots as colleagues, https://www.kuka.com/de-de/future-production/mensch-roboter-kollaboration/cobots (last accessed on 16 November 2023)
124 See Höpner, A. (2022)

It was only after the cobot specialist Universal Robots (see Figure 3-6), founded in 2008, successfully entered into this new market segment that many other players followed. Since then, international cobot specialists (e.g. Techman Robot from Taiwan, Doosan Robotics) as well as other globally active industrial robot manufacturers (e.g. FANUC, ABB) or national specialists (e.g. Franka Emika) have positioned themselves in this field.[125] In addition to its own cobot developments, Kawasaki Robotics[126] also decided to cooperate with the German start-up Neura Robotics.[127]

Figure 3-6: Provider example for cobots: Universal Robots

Cobots von Universal Robots	
Who is the provider?	Universal Robots was founded in 2005 as a start-up from a university project in Odense, Denmark. In 2015, the company was acquired by Teradyne, a US provider of automation solutions. The success of Universal Robots contributed to the development of a significant robotics cluster in Odense.
What is its position in the robotics value chain?	Universal Robots specialises in the development and construction of robot arms.
	In addition, the company relies on partnerships and suppliers, e.g. for more than 340 peripheral devices (including individual components, software, application kits and solutions).
	Customisation for the specific use case is carried out by a system integrator through needs-based configuration.
What is the offer?	The robot's ability to cooperate with humans is made possible by structural features (lightweight robotics), sensor technology and software.
	UR has developed five robot models, ranging from a simple lightweight robot/tabletop robot to a powerful industrial robot, which differ in terms of size/weight, reach and payload.
Who are the users?	Industrial companies, especially SMEs, from various sectors use UR robots for a wide range of applications (e.g. assembly, welding, material removal).
What is the benefit?	The key advantage results from the possibility of operating cobots within reach of people and dispensing with protective equipment. Compared to traditional industrial robots, cobots are significantly cheaper and more flexible to use.

Source: WIK based on publicly available information from Universal Robots

The high degree of specialisation and the additional market growth in industrial robotics generated by cobots, create sales potential for players who supply hard- and software or take over implementation services on user company's behalf.

125 See e.g. Verified Market Research (2021) and Wired Workers: From robot to cobot, a look at history, https://www.wiredworkers.io/de/vom-roboter-zum-cobot-ein-blick-in-die-ges-chichte/#:~:text=The%20first%20cobot%20was%20launched%20in%201996,Cobots%20on%20the%20market%20. (last accessed on 16.11.2023)

126 Japanese pioneer in the field of robotics who produced the first commercial industrial robot in Japan in 1969, https://kawasakirobotics.com/de/company/ (last accessed 16/11/2023)

127 See above (2023a)

3.2.4 Mobile autonomous robots

3.2.4.1 Status Quo

Stationary industrial robots, which are permanently installed in one place, are increasingly being supplemented by various forms of mobile robots that are able to move e.g. on wheels, chains or legs or fly as drones. The first developments in the field of mobile robotics began back in the mid-1980s.[128] Mobile robots can be used in industrial companies, particularly for a variety of tasks in production and logistics (e.g. pallet transport). In addition, mobile robots also take on recurring tasks in very specific fields of application or tasks that are harmful or difficult for humans in industrial plants (e.g. as inspection robots in hard-to-reach or hazardous environments).

Mobile robots belong to the segment of service robots deployed in industrial companies (see Chapter 2.1). This market segment is very small yet, but is characterised by significant growth. The main areas of application for industrial service robots are transport and logistics; other areas of application such as cleaning are less important (see also Chapter 2.2).[129]

The most widespread mobile robot variants to date can move within a very limited and predefined area. At present, many mobile robots are still hard-wired and are therefore restricted to a small radius. Mobile robots with a more extensive field of movement are usually implemented in the form of automated track-guided solutions (e.g. using magnetic tape, wire or laser reflectors) that perform transport tasks along predefined routes. However, these robots cannot cope with unforeseen changes. For example, obstacles in the specified route mean that their designated task cannot be fulfilled.

The current focus is on the development of autonomous mobile robots (AMR), humanoid robots and the further development of associated software solutions. AMRs are of particular importance to industrial user companies, while humanoid robots are still much less developed and focussed on specific fields of application.

In contrast to traditional automated guided vehicles (AGVs), autonomous mobile robots (AMRs) are not dependent on predefined lane guidance and can be quickly adapted to new production conditions, as they can recognise their environment in real time and move independently and safely within it.[130]

128 For the history, see e.g. Shneier, M.; Bostelman, R. (2015), pp. 1-5
129 See International Federation of Robotics (IFR) (2023c), p. 42
130 See also Giannetti, R. (2023)

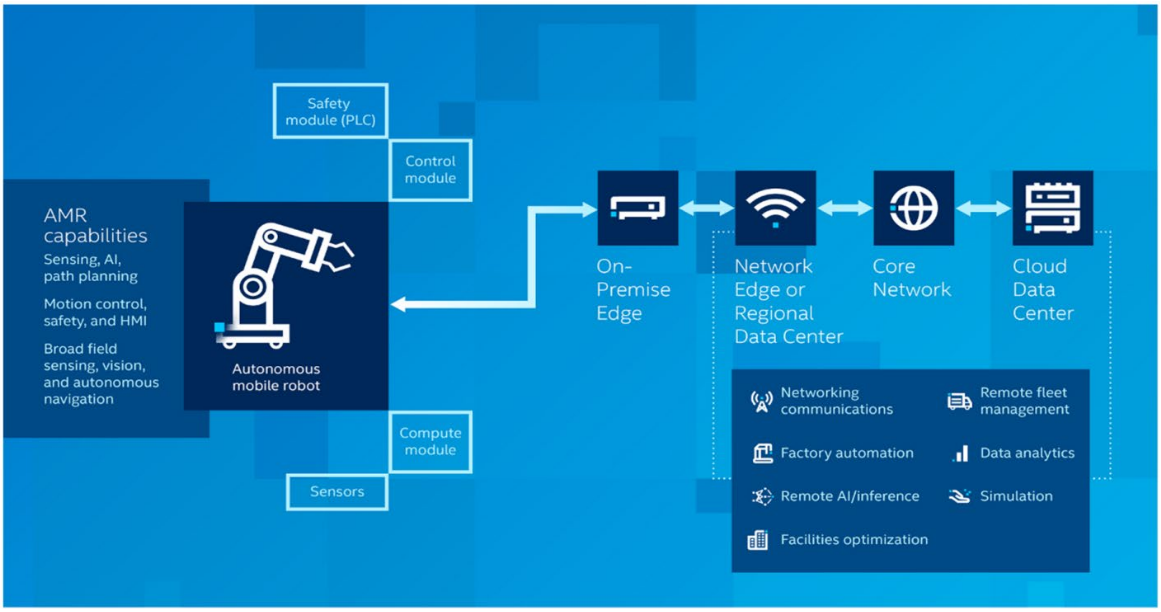
3.2.4.2 Contribution of innovative digital technologies

AMRs represent a new category of robots that can only be realised using digital technologies due to the intelligence required to act independently in changing environments. A large number of innovative hardware and software solutions are required for the development of AMR. This includes technologies described above needed for a simplified implementation and the fulfilling of complex tasks. AMRs also represent an important component of the smart factory.

The realisation of AMR depends on cameras and sensors that detect unexpected obstacles or unforeseen changes. In addition, navigation systems, software and AI are required to enable AMR to react dynamically to unexpected obstacles, avoid collisions and adapt routes in real time. AI technologies help to make AMR route planning even more efficient.[131]

Finally, AMR solutions require wireless connectivity to cloud services in order to process the data volumes generated in the operating processes and implement corresponding analysis and remote control options (see also Figure 3-7). The currently predominant WLAN connections of AMR will be converted to 5G in the future, as its technology-specific advantages have a high benefit for AMR.[132]

Figure 3-7: Components and architecture of intelligent mobile robots



Source: Raj, R.; Kos, A. (2022)[133] , p. 15

131 See Raj, R.; Kos, A. (2022), p. 10 f.
132 See e.g. Giannetti, R. (2023)
133 See Raj, R.; Kos, A. (2022), p. 15

3.2.4.3 Impact on the robotics value chain

The AMR market segment (as well as the entire market for service robotics) is characterised by greater diversity than the market for industrial robotics. [134]

Although AMR is also offered by global players such as FANUC and ABB, medium-sized companies dispose of larger market share than in industrial robotics.[135] German manufacturers also play a role in the AMR market alongside Asian manufacturers, who are strongly represented in service robotics. Leading German mechanical engineering companies (e.g. Dürr, Jungheinrich, Grenzebach) manufacture AMR, while system integrators (e.g. BÄR Automation GmbH) implement the robots at the sites of the user companies. German start-ups with a focus on software solutions for specific AMR applications (e.g. Energy Robotics in the field of inspection robots, see Figure 3-8) or robot manufacturing (e.g. Adlatus Robotics focussing on cleaning robots) have also entered the service robotics market. The large number of required components (cameras, sensors, etc.) and safety solutions are provided by the same suppliers as in the field of industrial robots. As wireless connectivity is essential for mobile autonomous robots, providers of corresponding solutions are more important here in comparison to other market segments such as collaborative robots.

134 See International Federation of Robotics (IFR) (2023c), p. 45-46
135 See e.g. WAKU Robotics (2023), p. 11

Figure 3-8: Provider example for AMR: Energy Robotics

Software solutions for inspection robots (Energy Robotics)	
Who is the provider?	Energy Robotics is a company founded in 2016 that emerged from TU Darmstadt and specialises in software for robotics solutions.
What is its position in the robotics value chain?	Energy Robotics offers software solutions for inspection tasks and works together with manufacturers of various robots (e.g. Boston Robotics, Rover Robotics).
	Energy Robotics uses the cloud solution from AWS.
What is the offer?	Different types of robots are able to move autonomously on oil and gas platforms, in chemical plants and power stations and inspect them in many different ways.
	They use cameras and sensors to detect unusual objects, processes, temperatures and other indicators.
	The Energy Robotics solution is realised via a hardware-independent robot operating system with cloud-based fleet management and AI-driven data analysis for industrial applications.
Who are the users?	The industry focus is on the oil, gas, chemical and energy sectors. Users include Shell, Meck, BASF, Eon and Evonik.
What is the benefit?	The automation of labour-intensive monitoring tasks can greatly reduce personnel costs. In addition, some systems are dangerous for people (e.g. risk of explosion in chemical plants) or difficult to access (e.g. oil platforms). Furthermore, operating information is provided that enables for example predictive maintenance and early detection of faults (e.g. gas leaks).

Source: Energy Robotics, https://de.energy-robotics.com/ (last accessed on 16/11/2023)

3.2.5 Robotics in the smart factory

3.2.5.1 Status Quo

A smart factory can be understood as a "future-proof factory" that is characterised by the digital interconnection of all elements of the value chain and acts as a basis for self-controlling and autonomous company processes.[136] In this scenario, the role of humans is mainly reduced to monitoring and planning activities.

Robots are a key component in the realisation of fully digitised factories.[137] Robot manufacturers emphasize the potential of robotics for the establishment of globally competitive production facilities. They argue that digital factories open up the opportunity to relocate production back to Germany ("reshoring").[138]

136 See Fraunhofer IML (2020), p. 1
137 On the role of robotics in smart factoring, see also Zhihao, L. et al. (2022) and Kunze, S. (2020)
138 This statement is supported, for example, by a survey commissioned by ABB Robotics, according to which 74% of European and 70% of US companies are planning to re-shore or near-shore their

The concept of the smart factory has been discussed and researched for around ten years, but realistically it is still more of a vision of the future (see chapter 3.2.5.3). Some exaggerated expectations have had to be revised in recent years due to technical and organisational challenges.[139] The realisation of needs-based connectivity for machines and robots is also one of the challenging tasks. Intensive work is currently being carried out on the wireless communication of machines and the use of 5G (e.g. in the Wireless Communications for Machines working group in the VDMA[140] and in the 5G testbeds of the 5G Alliance for Connected Industries and Automation (5G-ACIA)).[141]

All categories of robots - e.g. traditional industrial robots, cobots, service robots - and a variety of robotics applications are relevant for the smart factory. Traditional industrial robots are usually still implemented in companies on a stand-alone basis, i.e. they are not interconnected with other robots or machines.[142] If individual robots are connected to the internet, this is generally used to read machine data or to monitor their functionality remotely. Connectivity is typically realised via fixed networks (e.g. Industrial Ethernet). Service robots, on the other hand, are dependent on connectivity for their functionality, but make up a small proportion of all robotics installations in industry compared to industrial robots (see chapter 2.2). Currently, they are primarily connected via WLAN.

The interconnection of robots and their integration with other machines is an important intermediate step on the way to the increasingly digitised factory. Here, robots are used to fulfil more complex tasks together with other machines in order to carry out a complete process step (e.g. loading and unloading of machine tools by robots). Different types of robots, e.g. mobile robots and cobots, are often combined with each other.

With regard to the interconnection of robots with each other and with higher-level machine control systems, non-standardised interfaces can be seen as a major obstacle.[143] The leading robot manufacturers design their interfaces differently.[144] However, not only robotics, but also other components of the smart factory are characterised by a lack of standardisation. Various organisations aim at driving forward standardisation processes related to the smart factory, with ISO and IEEE playing a prominent role. However, the standards developed there are not yet widespread.[145]

production. In 2022 among 1,610 US and European companies, see https://new.abb.com/news/de/detail/100417/abb-nennt-die-wichtigsten-robotik-trends-fur-2023 (last accessed on 16/11/2023). Our study also included examples of companies that want to increase their vertical integration using robotics and strive for independence from suppliers.

139 See also Berger, R. (2023)

140 See the lines and already published results, e.g. a handbook on technology-neutral orientation in the field of industrial wireless communication technologies in the mechanical engineering ecosystem: https://www.vdma.org/wireless-communications-for-machines (last accessed on 16 November 2023)

141 See https://5g-acia.org/ (last accessed on 16/11/2023)

142 See also, for example, Curryier, E. (2023)

143 With regard to AMR, see e.g. Giannetti, R. (2023)

144 Kuka, Yaskawa and Stäubli offer open interfaces for robot control to common machine interfaces (PLCs), while ABB integrates the robots directly into the machine control system. See in detail e.g. o.V. (2021)

145 See Microsoft/Intel (2022), p. 37

The most ambitious smart factory projects have been implemented by large companies in the automotive industry. One of the pioneering projects is Mercedes-Benz's Factory 56 in Sindelfingen, which was opened in September 2020 and required an investment of around 730 million euros.[146] In this factory, 56 assembly systems and the conveyor technology are networked with each other via Wi-Fi and 5G, and traditional assembly lines are being replaced by mobile transport robots.[147] The robotics applications implemented there are provided by a wide range of robot manufacturers and other players in the robotics ecosystem. There are 550 mobile transport robots from Safelog alone in use.[148] Safelog is a German manufacturer of autonomous mobile robots that was founded in Munich in 2006 and emerged from an engineering office with testing activities in the automotive sector. [149]

Completely new factories (greenfield), however, are an exception. Instead, robots usually have to be integrated into existing production environments (brownfield) with heterogeneous and sometimes decades-old machine inventories.[150] Realistically, the digitalisation of factories is carried out step by step, whereby initial use cases can be introduced and then expanded or scaled.[151] The automotive and industrial supplier Schäffler is planning a digitalised production model for its 83 globally distributed plants by 2030 based on end-to-end machine connectivity. A key component is the gradual creation of digital images of production. These digital twins will also be used, among other things, to train a cobot during setup for a new work step.[152]

3.2.5.2 Contribution of innovative digital technologies

The smart factory cannot be realised without a broad spectrum of innovative digital technologies. A variety of digital solutions are required to analyse the extensive amounts of data to optimise production efficiency. This is done on the basis of fully interconnected systems and processes. All robotics applications - including industrial robots traditionally implemented "stand alone" - must be integrated into these increasingly networked production processes.[153] In an important intermediate stage on the way to the smart factory, individual robots are connected with each other and with other machines in a specific production section.

Wireless connectivity technologies play an important role for the realisation of smart factory projects. For innovative industrial applications (especially mobile autonomous

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146 See Mercedes-Benz (2020): Factory 56, https://group.mercedes-benz.com/innovation/digitalisierung/industrie-4-0/eroeffnung-factory-56.html (last accessed on 16/11/2023)
147 Here, for example, 550 mobile transport robots from Safelog alone are in use, for more details see above (2023b)
148 See above (2023b)
149 See https://www.safelog.de/unternehmen/ (last accessed on 13/12/2023)
150 See, for example, KUKA (2021)
151 See e.g. Technologie-Initiative SmartFactory KL e.V., Kaiserslautern, in relation to the automotive industry Tiedemann, Y. (2022)
152 See e.g. https://www.schaeffler.com/de/medien/storys/storys-digitalisierung/smart-factory/ (last accessed on 13/12/2023)
153 See in detail International Federation of Robotics (IFR) (2020)

robots), 5G offers particularly high potential for factory automation due to the technology-specific advantages in terms of bandwidth, latency and reliability.[154]

5G campus networks[155] provide a great scope for the realisation of smart factories and the use of robots, as they are highly adaptable to the specific needs of the industrial company and offer greatly improved control over quality and security compared to the "best effort" of public mobile networks.[156]

3.2.5.3 Impact on the robotics value chain

All players in the robotics and automation market may benefit from a fully digitised production: When highly complex smart factories are set up, components and expertise from all areas of the robotics value chain are required. The focus, however, is on providing networking solutions.

It can be assumed that smart factories will initially be set up by those industrial companies that are already users of traditional industrial robots (i.e. larger companies from the automotive and mechanical engineering sectors). The number of traditional industrial robots in use is less likely to expand in comparision to new types of robots (e.g. mobile autonomous transport robots, cobots, professionally used service robots for inspection and cleaning) and a wide range of automation and networking solutions.

The planning and implementation of smart factories for industrial user companies also requires a sophisticated project management. This creates an expanded field of activity for system integrators with comprehensive automation expertise who can bring together the diverse components at the user company in an overall concept. They are also highly relevant for the realisation of sub-projects for the smart factory or networked robot cells. SW Schwäbische Werkzeugmaschinen GmbH, for example, which designs customised solutions based on standardised hardware and software modules and also acts as a partner to KUKA, exploits this potential. For example, the company offers solutions for networked CNC[157] machining centres to create self-sufficient cells or production lines.[158]

Which individual players will benefit from the high value creation potential of the smart factory also depends on the design of the framework conditions in the areas of standardisation, IT security and platforms, among others. Here, complex issues must be

154 See e.g. Schulz, D. (2021), p. 33
155 The type of implementation of the 5G network, e.g. stand-alone or non-stand-alone, or the type of 5G utilisation by the user company (e.g. private campus network or public mobile network) plays a role in the implementation options. As the rollout of the 5G network is still at an early stage, these are also the corresponding 5G robotics applications.
156 However, some of these advantages can also be achieved via network slicing or spectrum leasing, see GSMA (2022)
157 Computerised Numerical Control machines are machine tools that have control technology and can produce workpieces with high precision
158 https://sw-machines.com/produkte/automation/?gclid=EAIaIQobChMIofiOvouYgQMVJ4poCR2VDAq-MEAMYASAAEgLTsPD_BwE (last accessed on 16/11/2023)

resolved whose impact on the competitiveness of the market players involved is difficult to predict.

Major players in the robotics ecosystem are a driving force in the design of smart factories in many respects. On the one hand, their size and resources make them important partners in research projects, initiatives and industry working groups that focus on improving the framework conditions (e.g. within the VDMA, 5G ACIA). They are working intensively on the potential that 5G offers for robotics and are involved in ongoing research projects with partners.[159] Robotics is an important use case in current 5G research projects (e.g. at the 5G Industry Campus in Aachen[160]). KUKA has set up a 5G campus network at its main site in Augsburg, where smart production is being trialled.[161] ABB is conducting tests to realise 5G connectivity for industrial robots in cooperation with Ericsson.[162]

159 See e.g. ABB (2020)
160 https://5g-industry-campus.com/use-cases/ (last accessed on 16/11/2023)
161 See KUKA (2022)
162 See 5GACIA: 5G-Based Industrial Robotics, https://5g-acia.org/testbeds/5g-based-industrial-robotics/ (last accessed on 16 November 2023)

4 Conclusion

Innovative digital technologies - particularly in the areas of sensor technology, software/AI and cloud - enable further and new developments in the robotics offering, which can overcome existing barriers to broader market penetration and create additional sales potential in the robotics market.

Barriers to entry for small and medium-sized companies that lack expertise and financial resources are being significantly lowered by the increasing ease of implementation and greater user-friendliness of robots in the ongoing utilisation process. In addition, the increasing ability of industrially deployed robots to handle complex tasks also makes robotics attractive for those industrial companies whose production is characterised by a high diversity. In addition, collaborative robots complement the traditional robotics systems of large industrial companies and open up utilisation potential in SMEs that have not previously invested in industrial robotics for cost and space reasons.

Some further developments in robotics can only be realised through interconnection. For example, mobile autonomous robots are a new robot variant in the field of professional service robotics that is based on wireless networking and can be used primarily in the transport sector and for specific tasks such as inspection. These also play a role in the smart factory, which can still be seen as a vision of the future and in which the aim is to fully interconnect all machines, systems and processes.

The robotics market is gradually changing as a result of digitalisation and, unlike in other markets, this is not leading to disruptive developments that make existing industrial robotics business models obsolete.

Rather, the changes driven by digitalisation are gradually creating additional sales potential in the market for industrial robotics applications, from which a wide range of players in the robotics ecosystem may benefit.

It can be observed that the diversity of suppliers and the high degree of specialisation in the robotics market is increasing even further due to the growing importance of innovative digital technologies. Against this backdrop, cooperations that bring together specialists at different levels and also involve global players are becoming even more important.

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