Procedia CIRP 97 (2020) 45–50

Contents lists available at ScienceDirect

Procedia CIRP

journal homepage: www.elsevier.com/locate/procir

Digital innovation hubs for robotics – TRINITY approach for distributing knowledge via modular use case demonstrations

Minna Lanz[a,*], Jan Reimann[b], Aleš Ude[c], Niki Kousi[d], Roel Pieters[a], Morteza Dianatfar[a], Sotiris Makris[d]

[a] *Tampere University, Tampere, Finland*
[b] *Fraunhofer Institute for Machine Tools and Forming Technology IWU, Chemnitz, Germany*
[c] *Jožef Stefan Institute, Ljubljana, Slovenia*
[d] *University of Patras, Patras, Greece*

ARTICLE INFO

Article history:
Received 7 October 2019
Revised 25 April 2020
Accepted 18 May 2020

Keywords:
Digital innovation hub
Modular
Robotics
ICT
IIoT

ABSTRACT

Robots are no longer stand-alone systems on the factory floor. The demand for industrial robots (market) is anticipated to be growing to 65 billion euros by the year 2023. Within all areas of robotics, the demand for collaborative and more flexible systems is rising as well. The level of desired collaboration and increased flexibility will only be reached if the systems are developed as a whole, e.g. perception, reasoning and physical manipulation. The rising need for collaborative robots in the automation industry is acting as a driver for this market and is expected to serve as a market opportunity for future growth. However, at the same time especially smaller companies have difficulties to formulate a concrete vision and strategies for the uptake of robotics, finding skilled workforce to develop and deploy the robot systems and/or work in the manufacturing industry. A number of Digital Innovation Hubs (DIHs) have been developed to enhance the knowledge and technology transfer from laboratories to factory floors, mitigating the skills gap and supporting the formulation of innovation ecosystems with the specific focus on small and medium-sized companies around Europe. The main aim of this paper is to introduce the concept and approach taken in H2020 TRINITY-project that aims to develop a Robotics Innovation Hub focused on Agile Production. The paper will introduce the concept and technical approach of the project, and discusses the preliminary results, challenges and opportunities of these kind of DIHs.

1. Introduction

Manufacturing sector is the back-bone of the European welfare society. It requires constant modernisation and development in order to stay competitive in the global markets. Re-industrialisation requires major strategic initiatives under a European umbrella with significant public and private investments. Digitalisation, AI and robotisation are often seen as a threat, but are in fact an enormous opportunity. Collaborative robots, or cobots, are intended to work alongside or interact with humans in a shared space (Vanderborght, 2020). The main objective of TRINITY[1] project is to create a network of local digital innovation hubs (DIHs) composed of research centers, companies, and university groups that cover a wide range of topics that can contribute to agile production. In TRINITY the main three themes that were taken into focus are advanced robotics, digital tools and platforms, and Cyber-Security technologies, hence the name TRINITY. These three themes were seen as main drivers to support the uptake of advanced robotic systems in the field of discrete production. TRINITY aims to be a one-stop shop for robotics methods and tools to achieve intelligent, agile and re-configurable production. The network will start its operation by developing demonstrators in the areas of robotics we identified as the most promising to advance agile production, e.g. collaborative robotics including sensory systems to ensure safety, effective user interfaces based on augmented reality and speech, re-configurable robot workcells and peripheral equipment (fixtures, jigs, grippers,...), programming by demonstration, Internet of Things (IoT), secure wireless networks, etc. These use case demonstrators will serve as reference implementations for two rounds of open calls for application experiments. The TRINITY

* Corresponding author.
E-mail address: minna.lanz@tuni.fi (M. Lanz).

[1] https://trinityrobotics.eu/

https://doi.org/10.1016/j.procir.2020.05.203

project focuses on supporting Small and Medium sized Enterprises (SMEs) to uptake robotics. Roughly 85 percent European companies are SMEs. Most of these have moderate capabilities to do advanced development by themselves. With the cascade funding, appr. 8 million EUR, TRINITY aims to support 25–40 prototyping projects envisioned and executed by the SMEs.

Besides technology-centered services, TRINITY's network of DIHs will also offer training (adult learning) and consulting services (technology, tools, standards and research collaboration), including support for business planning and access to financing. Services of participating DIHs and dissemination of information to the wider public will be provided through a digital access point that will be developed in the project. Another important activity of the project will be the preparation of a business plan to sustain the network after the end of the project funding.

The aim of this paper is to introduce the background for the technical approach of the TRINITY project. Thus the focus is on the modularisation and standardization of the technical developments in the project realised as internal use case demonstrations.

2. Theoretical background

2.1. Modularity

The product architecture, the way product components and functions are arranged into chunks or modules, has a significant effect on the product development process and on the whole product life-cycle. It may affect the efficiency of the product design on the three dimensions of sustainability (economic, ecologic and social) and, therefore, be an influencing aspect of sustainable product design (Bonvoisin et al., 2016). In principle, modules are defined as physical structures that have a one-to-one correspondence with functional structures. They can be thought of quite simply as building blocks with well-defined and described interfaces (Ericsson and Erixon, 1999). Modularisation of the products is a strategy that has been proven useful in a large number of fields dealing with complex systems and is utilized for different functional purposes, e.g., product design, production, and use (Asadi et al., 2019). Pakkanen et al. Pakkanen et al. (2016) emphasize that the focus should be on designing products so that reusable sections can be separated from varying sections because of customer specific needs.

2.2. Advanced and interactive robotics

Research and technical development on Human-Robot Collaboration (HRC) has shown progress in recent years (Halme et al., 2018). Wang et al. Wang et al. (2017) extended the traditional concept of HRC to more symbiotic collaboration which extends the HRC by several key characteristics such as

- intuitive and multi-modal programming environment: workers do not need prior in-depth knowledge of the system,
- zero-programming: ideally, the workers can work with the robots via gestures, voice commands, and other forms of natural inputsvwithout the need of coding,
- immersive collaboration: with the help of different devices, e.g. screens, goggles, wearable displays, the workers can collaborate with the robots with actively engaged senses, and
- context/situation dependency: the system should be capable of interleaving autonomous human with robot decisions based on trustworthy inputs from on-site sensors and monitors inspecting both humans and robots.

Current European safety regulations in practice require complete physical separation between people and industrial robots. This is traditionally achieved using fences or similar physical barriers as a precaution to ensuring safety (Halme et al., 2018; Hietanen et al., 2020). Given the safety issues that arise from the coexistence of robots and humans, the means of detecting and monitoring human presence and adjusting the robots' behaviour, need to be researched (Michalos et al., 2014).

2.3. Internet of Things

The business world is highly competitive, and in order to successfully tackle everyday challenges, operational managers and executives demand high dependability and wide visibility within their business process networks. However, in order to provide up-to-date information and be able to react in a flexible and optimal way to changing conditions, real-time information from the factory system is needed (Colombo et al., 2010). For that reason the authors of Reimann and Sziebig (2019) introduced the concept of the *Intelligent Factory Space* which describes a multi-layer and modular reference architecture for the synergy of machines (such as robots) and humans in order to increase productivity and quality.

Information and Communication Technology (ICT) has significantly changed assembly systems in the past years, partly due to the massive connectivity of components and actors (LAN, Wi-Fi, Bluetooth, near field communication, etc.), and partly due to increasing process observability and local computing capacity in smart devices (automatic identification, sensors, wearable devices, smart tags, etc.) (Wang et al., 2017). As a consequence, such systems span a fog architecture (Bonomi et al., 2012) containing various edge devices which shift computing capacity closely to the source of the produced data: the smart devices.

The Internet of Things (IoT) evolved a lot in the last decade. For the purpose of this paper it simply denotes the interconnection of heterogeneous (computing) devices, such as mobile phones, machines or humans, over a network beyond physical limitations like companies, buildings or a Local Area Network (LAN). The term Industrial IoT (IIoT) considers the IoT in an industrial context. This means that systems in manufacturing and production environments communicate with each other and use industrial communication channels, standards and technologies, e.g. OPC-UA or PROFINET (Reiman and Sziebig, 2019). IIoT targets at connecting different manufacturing data sources, such as sensors, business logic for making decisions based on sensor data, machines to be controlled and other actuators (e.g. industrial robots) in order to increase efficiency of production and make manufacturing smarter. This architecture is considered to be a fog architecture where every layer has a specific purpose and data is processed further as near at the data source as possible in order to decrease throughput of data and to minimise latency.

2.4. Cyber security

Due to the fact that aforementioned (I)IoT solutions and fog architecture is very data intensive, and robots are connected to such architecture, and, therefore, are integrated and controlled through existing IT infrastructure, the aspect of cyber security must not be omitted. On the one hand, respecting data privacy and also securing data streams is essential and state of the art.

On the other hand, robots are vulnerable (Vilches et al., 2018), too, and can cause much harm when not integrated cyber securely. Robots are connected to both the physical and the digital world and therefore can be considered a Cyber-Physical System (CPS) on its own (Khalid et al., 2018). As a consequence, attacking a robot from the digital may imply that it not only malfunctions or the attacker can take control. Even worse is the implication that an attack may result in real physical dangers, be it to machines but also to humans. This is required to be avoided at all cost and,

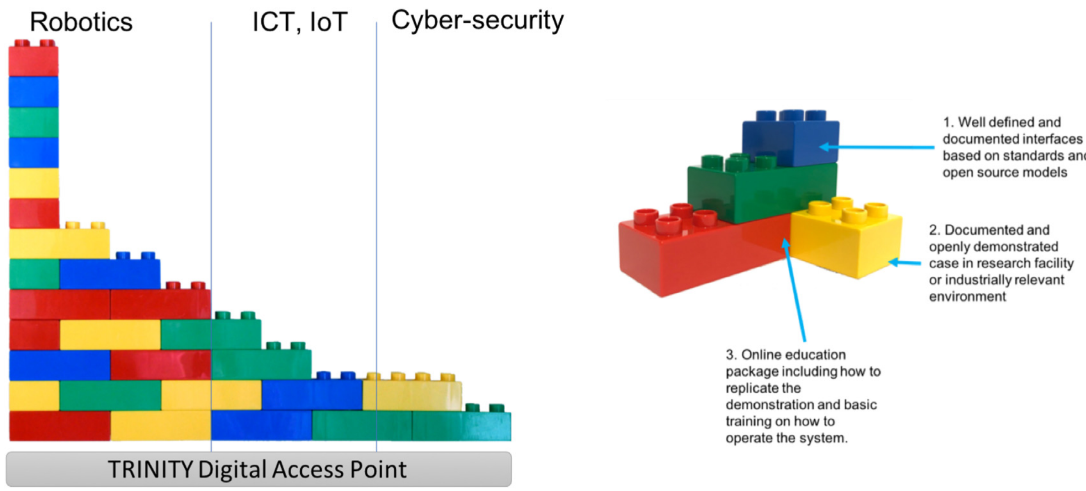

Fig. 1. TRINITY modular approach for use case development.

thus, Cyber-Security aspects will be matured further through TRINITY and will be made available and transferred to partners and the community.

3. TRINITY approach

The TRINITY mindset is based on the following assumptions regarding the state of the art in industry and challenges companies are facing with emerging technologies.

- *Assumption 1*: The lack of working examples prevents the companies to explore possibilities of emerging technologies. In the daily operations the focus is on the short term problem solving. However, the uptake of these technologies will take time and several trials. The concrete examples on how to combine different technologies and methods will help the companies to do development by themselves as well.
- *Assumption 2*: In SMEs, training needs arise from the increased use of multitude of digital manufacturing tools, advanced robotics, new additive manufacturing processes, and Safety and Cyber-Security challenges. The key challenge in addressing the evolution of future education in the manufacturing sector involves developing skills and expertise as well as pedagogical and technological approaches that match the changing needs of today's and future workplaces.

3.1. Use case demonstrations and technical modules

The use case demonstrations are based on the preliminary assumptions. We argue that few-of-a-kind or even one-of-a kind production can only be realised if set-up times of new production processes are not very long. Besides easy programming, the reduction of set-up times can also be supported by innovative reconfiguration technologies, e.g. passively re-configurable fixtures (Gašpar et al., 2020). Such elements can facilitate the preparation of the robot's workspace and tools. Supported by advanced control programs and tool changers, a robot can prepare its tooling and workspace by itself. This way we can significantly improve the flexibility of robotic systems since new tasks cannot be quickly implemented just in software, but also require hardware changes. In this context, especially passively re-configurable hardware and software systems and 3D printing technologies are of interest.

The main target is to prepare modular and re-configurable use-case demonstrations on the fields of robotics, ICT and IoT, and Cyber-Security (see Fig. 1, left side). Each of the use case demonstrations include well defined specifications, 'how to set up' tutorials and 'how to use' education packages, illustrated in the Fig. 1, right side. The technologies we use are cross-sectorial, and can be combined to fit the purpose. In order to ensure that different technologies can be combined with minimum effort we have divided the technical developments (e.g. code, hardware, etc) into smaller well-defined modules. The modules in TRINITY-project's use case demonstrations are typically self-contained pieces of hardware and/or software, which can be offered to industrial partners for integration in their production processes. The principles of modularization have been applied for defining the basic modules that can be delivered for each use case e.g. the modules deliver one or two main functionalities, and the functionality is not shared between modules. The main idea is to build a catalog of use case demonstrations using the developed modules as a showcase for the companies. The idea of the modules is depicted in the left side of Fig. 1. As the project is strongly focused on the robotics technologies, we expect that the majority of the modules will be related to robotics, then to IoT/ICT and finally to Cyber-Security.

We defined 18 internal use case demonstrations to showcase novel robotic and related technologies that have the potential to increase the agility of production processes in industrially relevant environments (TRL 5 and above). The thematic areas in TRINITY are robotics, IoT and ICT/IoT/IIoT, and Cyber-Security, illustrated in Fig. 2. While the internal demonstrators are at different stages of development at the moment, their initial descriptions have already been published at https://trinityrobotics.eu/demonstrators/. All demonstrators are composed of and use different reusable modules.

The use case demonstrations listed in Fig. 2 are implemented based on the developed modules. Currently we have 22 modules publicly available or in progress. Most of the robotics-related modules and use cases follow the available standards: ISO 10218-1/2 ISO 10218-1/2:2011 (2011) and ISO/TS 15066 ISO/TS 15066:2016 (2016). In the current state of the TRINITY project, a number of modules with interface descriptions and technical specifications have been been made available to potential external users. More will be published as the project progresses.

The TRINITY use case demonstrations, further elaborated in Table 1, rely on robotics, artificial intelligence and Cyber-Security with the aim to improve the agility and performance in manufacturing activities, and to generate new products and service concepts in the field of robotics. The results from these are expected to make few-of-a-kind production economically feasible, it will improve productivity and quality, allow robots and humans to coexist safely, provide intuitive user interfaces, and allow task con-

Table 1
Summary of the internal use case demonstrations in the TRINITY.

No	Name	Main goals	Theme	Standards and tools	references
1	Collaborative assembly with vision-based safety system	To provide safe and intuitive robotic interface for human-robot collaboration.	Robotics	ISO/TS 15066:2016, ISO 10218-1/2, ROS	Hietanen et al. (2020)
2	Collaborative disassembly with augmented reality interaction	To provide safe and intuitive robotic interface for multi-machine work environments, where the human worker operates together with traditional industrial robots (payload up to 50kg) and mobile robots.	Robotics	ISO/TS 15066:2016, ISO 10218-1/2, ROS	N/A
3	Collaborative robotics in large scale assembly, material handling and processing	To show possibilities for utilization of agile human robot collaboration in large scale material handling, processing or assembly tasks, which are needed e.g. in the prefabrication of a wall element.	Robotics	ISO/TS 15066:2016, ISO 10218-1/2	N/A
4	Integrating digital context (e.g. BIM) to the digital twin with AR/VR of the robotized production	The main goal here is to utilize of digital context and digital twins for the robotized production and enhance the user experience with AR/VR.	Robotics	ISO/TS 15066:2016	N/A
5	Wire arc additive manufacturing with industrial robots	The main goal of this demonstration is to demonstrate on how to increase production rate with additive manufacturing of metal parts	Robotics	ISO 10303, ISO 6983, NS-EN 1011-1:2009	N/A
6	Production flow simulation/supervision	The goal in this demonstration is to provide a visualization of production, along with distant monitoring/control of production flow with low-cost sensors/computing.	ICT, IoT	ISO 10303	N/A
7	Robot workcell reconfiguration	The goal is to provide the manufacturing SMEs and also larger manufacturing companies effective software and hardware components to quickly reconfigure manufacturing workcells in order to quickly switch from one production process to another.	Robotics, ICT	ISO/TS 15066:2016, ISO 10218-1/2, ROS-I	Gašpar et al. (2020)
8	Efficient programming of robot tasks by human demonstration	In this demonstrator, we address programmability challenges and increase the value added by providing a software and hardware framework that include both front-end and back-end solutions to integrate programming by demonstration paradigm based on kinesthetic teaching into an effective system for programming of robot tasks.	Robotics	ISO/TS15066:2016, ISO10218-1/2, ROS-I	Gašpar et al. (2020); Nemec et al. (2018)
9	Dynamic task planning and work re-organization	The core objective is to support production designers during the manufacturing system design process and reduce the time and size of the design team needed for applying a change in the existing line.	ICT, IoT	N/A	Tsarouchi et al. (2017)
10	HRI framework for operator support application in human robot collaborative operations	This use-case demonstration aims at increasing operator's safety feeling and acceptance when working close to large industrial robots by visualizing data coming from a robot's controller and by displaying visual alerts to increase their awareness for a potentially hazardous situation.	ICT, IoT	ISO/TS 15066:2016, ISO 10218-1/2.	Michalos et al. (2018); Papanastasiou et al. (2019)
11	Robotized serving of automated warehouse	The goal is to demonstrate the feasibility of using mobile robots in intralogistics.	Robotics	N/A	N/A
12	User-friendly human-robot collaborative tasks programming	The following use case introduces a new method of programming robotic applications which is intuitive, user-friendly and requires no prior robot programming expertise.	Robotics	ISO/TS 15066:2016, ISO 10218-1/2, ISA-95	N/A
13	Deployment of mobile robots in collaborative work cell for assembly of product variants	The following use case introduces mobile robots equipped with manipulators in a shared workplace to assist assembly operations in a collaborative work cell for assembly of product variants.	Robotics	ISO/TS 15066:2016	N/A
14	Virtualization of a robot cell with a real controller	The aim of this demonstrator is to create a safe virtual environment for training, testing and simulation purposes in the context of metal cutting processes.	Robotics	N/A	N/A
15	IIoT Robustness Simulation	The goals are to increase robustness of wireless networks in production/IIoT environments.	ICT, IoT, Cyber Security	IEEE 802.15.4, IEEE 802.11, CUDA, OpenCL	N/A
16	Flexible automation for agile production	The main goal is to demonstrate flexible handling solutions for assembly process.	Robotics	..	N/A
17	Artificial intelligence based stereo vision system for object detection, recognition, classification and pick-up by a robotic arm	The goal is to enable automation of industrial processes involving large number of different kind of objects with unpredictable positions.	Robotics	ROS	N/A
18	Rapid development, testing and validation of large scale wireless sensor networks for production environment	The goal is to decrease time to market for large scale WSN implementation in production environment.	ICT, IoT	EDI TestBed	N/A

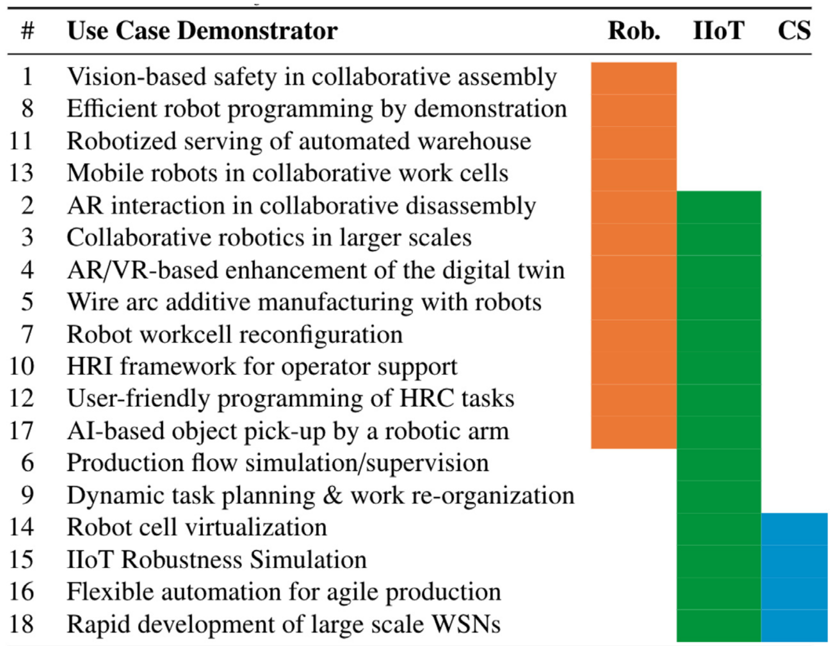

Fig. 2. TRINITY use cases in thematic areas of the project scope.

figuration to become adaptive. The use case demonstrations carried out by the consortium members are carefully selected based on local industrial needs and by using industrially relevant environments in collaboration with local and regional companies. The modules are distributed from the developed central storage named as TRINITY Digital Access Point.

3.2. Approach to education and training

The emerging technologies are characterised as having real-time, adaptive, decentralised decision-making and self-optimising features (Reimann and Sziebig, 2019). Future working-life technologies are considered disruptive by nature; thus, when applied to practice, they will demand a completely new set of skills and mindsets from workers. In order to stay competitive, companies and their workers need to be able to quickly adapt to new market conditions and customer needs, which require more and more problem-solving skills. To meet these needs, education demands for novel pedagogical and technological learning approaches to enhance and trigger workers' skills. The core idea in the TRINITY is to develop the training material for each module and use case demonstration. The education material relating to the use case demonstrations is also modularised. This means that the exercises are developed for three levels, beginning, intermediate and expert.

4. Conclusions and future work

The manufacturing industry is a core element of the value chain and is critical to ensure a balanced labour market and skills pyramid. Moreover, industry and services go hand in hand and need each other. De-industrialisation weakens the European middle class and will cause a mismatch of supply and demand on the labour market as discussed by Vanderborght (2020). The main reason for Digital Innovation Hubs establishment is the improvement for knowledge and technology transfer from laboratories to factory floor, mitigate the skills gap and support formulation of innovation ecosystems. The DIHs should also contribute strongly to the digital transformation of small and medium-sized companies around Europe. The main aim of the paper was to introduce TRINITY-project's main concept and technical approach to attract the SMEs to join to the TRINITY community (or ecosystem)is to showcase concrete use case demonstrations that could support their own digital transformation. The paper introduced the use case demonstrations that can further be realised with a number technical modules. The future work will include more detailed interface descriptions, technical specification and training material for these modules. Also the support for the Open Call 1 external use case demonstrations will be provided.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 825196.

References

Asadi, N., Jackson, M., Fundin, A., 2019. Implications of realizing mix flexibility in assembly systems for product modularity - a case study. Journal of Manufacturing Systems 52, 13–22. Part A

Bonomi, F., Milito, R., Zhu, J., Addepalli, S., 2012. Fog computing and its role in the internet of things. In: MCC'12: Proceedings of the First Edition of the MCC Workshop on Mobile Cloud Computing. ACM, pp. 13–16.

Bonvoisin, J., Halstenberg, F., Buchert, T., Stark, R., 2016. A systematic literature review on modular product design. J. Eng. Des. 27 (7).

Colombo, A.W., Karnouskos, S., Mendes, J.M., 2010. Factory of the future: A service-oriented system of modular, dynamic reconfigurable and collaborative systems. In: Benyoucef, L., Grabot, B. (Eds.), Artificial Intelligence Techniques for Networked Manufacturing Enterprises Management. Springer, London, pp. 459–481. Springer Series in Advanced Manufacturing

Ericsson, A., Erixon, G., 1999. Controlling Design Variants: Modular Product Platforms. ASME press, New York, NY, USA.

Gašpar, T., Deniša, M., Radanovič, P., Ridge, B., Savarimuthu, T.R., Kramberger, A., Priggemeyer, M., Roßmann, J., Wörgötter, F., Ivanovska, T., Parizi, S., Gosar, Z., Kovač, I., Ude, A., 2020. Smart hardware integration with advanced robot programming technologies for efficient reconfiguration of robot workcells. Robot. Comput. Integr. Manuf..

Halme, R.-J., Lanz, M., Kamarainen, J., Pieters, R., Latokartano, J., Hietanen, A., 2018. Review of vision-based safety systems for human-robot collaboration. In: Procedia CIRP, 72, pp. 111–116.

Hietanen, A., Pieters, R., Lanz, M., Latokartano, J., Kamarainen, J.K., 2020. AR-based interaction for human-robot collaborative manufacturing. Robot. Comput.-Integr. Manuf. 63, 101891.

ISO 10218-1/2:2011, 2011. Robots and robotic devices and safety requirements for industrial robots. Part 1: Robots/Part 2: Robot Systems and Integration.

ISO/TS 15066:2016, 2016. Robots and robotic devices and collaborative robots.
Khalid, A., Kirisci, P., Khan, Z.H., Ghrairi, Z., Thoben, K.-D., Pannek, J., 2018. Security framework for industrial collaborative robotic cyber-physical systems. Comput. Ind. 97, 132–145.
Michalos, G., Kousi, N., Karagiannis, P., Gkournelos, C., Dimoulas, K., Koukas, S., Baris, K., Papavasileiou, A., Makris, S., 2018. Seamless human robot collaborative assembly an automotive case study. Mechatronics 194–211.
Michalos, G., Makris, S., Spiliotopoulos, J., Misios, I., Tsarouchi, P., Chryssolouris, G., 2014. ROBO-PARTNER: Seamless human-robot cooperation for intelligent, flexible and safe operations in the assembly factories of the future. In: Procedia CIRP, 23, pp. 71–76.
Nemec, B., Likar, N., Gams, A., Ude, A., 2018. Human robot cooperation with compliance adaptation along the motion trajectory. Auton. Robots 42 (5), 1023–1035.
Pakkanen, P., Huhtala, P., Juuti, T., Lehtonen, T., 2016. Achieving benefits with design reuse in manufacturing industry. In: Procedia CIRP, 50, pp. 8–13.
Papanastasiou, S., Kousi, N., Karagiannis, P., Gkournelos, C., Papavasileiou, A., Dimoulas, K., Baris, K., Koukas, S., Michalos, G., Makris, S., 2019. Towards seamless human robot collaboration: integrating multimodal interaction. Int. J. Adv. Manuf.Technol. 1–17.
Reimann, J., Sziebig, G., 2019. The intelligent factory space – a concept for observing, learning and communicating in the digitalized factory. IEEE Access. ISSN 2169-3536
Tsarouchi, P., Michalos, G., Makris, S., Athanasatos, T., Dimoulas, K., Chryssolouris, G., 2017. On a human-robot workplace design and task allocation system. Int. J. Comput. Integr.Manuf. 30 (12), 1272–1279.
Vanderborght, B., 2020. Unlocking the Potential of Industrial Human-Robot Collaboration – a Vision on Industrial Collaborative Robots for Economy and Society. Directorate-General for Research and Innovation (European Commission).
Vilches, V. M., Gil-Uriarte, E., Ugarte, I. Z., Mendia, G. O., Pisón, R. I., Kirschgens, L. A., Calvo, A. B., Cordero, A. H., Apa, L., Cerrudo, C., 2018. Towards an open standard for assessing the severity of robot security vulnerabilities, the robot vulnerability scoring system (RVSS). arXiv:1807.10357.
Wang, X.V., Kemeny, Z., Vancza, J., Wang, L., 2017. Human-robot collaborative assembly in cyber-physical production: classification framework and implementation. CIRP Ann. – Manuf. Technol. 66, 5–8.