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Open-Digital-Industrial and Networking pilot lines using modular components for scalable production – ODIN project approach

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Abstract

While robots have very well proven their flexibility and efficiency in mass production and are recognized as the production resource of the future, their adoption in lower volume, diverse environment is heavily constrained. The main reason for this is the high integration and deployment complexity that overshadows the performance benefits of this technology. This paper presents the vision of ODIN European funded project which is to strengthen the EU production companies' trust in utilizing advanced robotics, by demonstrating that novel robot-based production systems are not only technically feasible, but also efficient and sustainable for immediate introduction at the shopfloor. To achieve that, ODIN brings together, by means of hardware and software, the latest technological advancements in the fields of a) collaborating robots and human robot collaborative workplaces, b) autonomous robotics and AI based task planning, c) mobile robots and reconfigurable tooling, d) Digital Twins and Virtual Commissioning and e) Service Oriented Robotics Integration and Communication Architectures. ODIN will provide a systematic approach for integrating these technologies under modular and reconfigurable large-scale robotic pilots. The performance of these robotic pilots will be tested and validated in three case studies, from the automotive, the white goods and the aeronautics industry.

Keywords: advanced robotics; human robot collaboration; perception; digital; large scale pilot lines;

1. Introduction

Nowadays, robots are widely used in multiple sectors of manufacturing in order to handle tasks requiring high skills of flexibility. However, the use of robots is not yet fully adopted in industrial environments with different diversities and volumes of production [1] due to their high integration effort.

If robots are to become well accepted across the whole spectra of production industries, real evidence that they can operate in an open, modular and scalable way is needed. Such an approach needs to demonstrate:

- Easy customization and deploy ability: allowing core technologies (additional robotic units, individual sensing [2] / perception [3]/ networking systems) to be easily integrated

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- Autonomy through real collaboration of robots, allowing them to perform tasks in a non-sequential, non-pre-programmed and non-separated way of operation [4]
- Appropriateness of robotic technology for different production tasks through support of different robot types and tooling [5] reconfigured for the particular process
- Compatibility with existing production processes and already installed production systems
- Robustness through autonomy: ability to operate with very low degree of supervision

This paper discusses the concept of the EU project ODIN (http://odin-h2020.eu/) that aims to address the abovementioned aspects. ODIN aspires to fill this gap by bringing technology from the latest groundbreaking research in the fields of a) collaborating robots and human robot collaborative workplaces [6], b) autonomous robotics and AI based task planning [7], c) mobile robots and reconfigurable tooling [8], d) Digital Twins [9], [10] and Virtual Commissioning [11] and e) Service Oriented Robotics Integration and Communication Architectures. To strengthen the EU production companies' trust in utilizing advanced robotics, the vision of ODIN is: "to demonstrate that novel robot-based production systems are not only technically feasible, but also efficient and sustainable for immediate introduction at the shopfloor".

2. ODIN Approach

ODIN encompasses the concept of modular and reconfigurable robots-based production and will work towards two key dimensions according to the Multi Annual Research agenda by euRobotics:

- **Modularity**: Reusable software/hardware components and modular integration schemes for reduction of deployment costs and diminishing the need for re-factoring efforts when presented with different domains.
- **Scalability**: Robotic applications making use of modularity principles, being able to adjust their structure and behavior to suit the needs from "small footprint-low volume" to "large facility-mass volume" production.

Both principles require that different technologies can be brought together by means of hardware, control software and networking interfaces. They also require that these individual technologies can be customized to perform different operations either by changing their physical structure or their operating parameters. To achieve its primary objective and as its name suggests, ODIN relies on the concept of pilot lines that encompass four major components: Open, Digital, Industrial and Networked as shown in Fig. 1.

3. Open Component (OC)

The Open Component (OC) is a small footprint, small scale pilot instance allowing the development, integration and testing of cutting-edge technologies. Its purpose is to deploy and validate robotic technologies using an open approach before these can be deployed in industry. The enabling technologies considered in ODIN are presented in the following subsections.

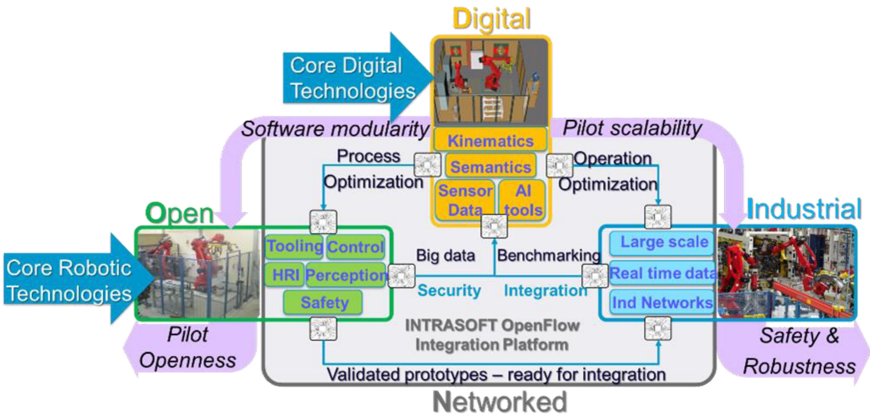

Fig. 1. ODIN Approach to modular ad reconfigurable robotic pilot

3.1. Autonomous mobile manipulators

Due to the recent paradigm shift, manufacturing processes have moved from mass manufacturing to highly customized small batches [12]. For this reason, robotics had to be updated and provide robots with a greater capacity for perception and autonomy. The rise of autonomous industrial mobile handlers (AIMM) [13] is present in more and more sectors of the current industry. These innovative robots have great versatility by combining two technologies widely used in the industry: autonomous navigation systems and manipulation with collaborative arms. ODIN will adopt, enhance and customize autonomous mobile manipulators for different production scenarios. Indicative examples are the COMAU mobile platform (a) which is composed by the Racer5 Cobot and Agile1500 AGV, (b) robout which is composed by two KUKA IIWA robot arms on a customized Robotnik platform and (c) the AIC robot composed by one ABB IRB 4600 robot arm mounted on a customized AGV (Fig. 2). Depending on the task, the selected robot will be refurbished to create a new generation robot that incorporates the ODIN technologies to provide advanced solutions to the use-case challenges.

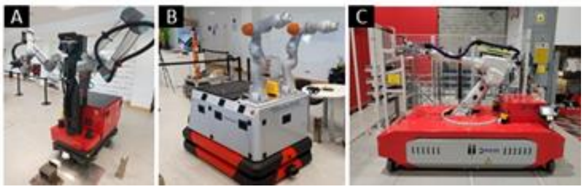

Fig. 2. (a) Comau mobile platform (b) robout robot (c) AIC mobile platform

3.2. Reconfigurable robot tooling

Reconfiguration performance in robot tools depends on the ability to adapt to production changes. Traditionally, industrial grippers are productive although very specialized to one object type. The main factors for designing reconfigurable tooling are the weight, flexibility, reliability, stock keeping, maintenance and design simplicity. Based on these factors, a high-speed reconfigurable gripper will be designed and implemented in ODIN that is capable of handling parts of different shapes and geometries as well as a robot end-effector with in-hand manipulation capabilities (Fig. 3). The difficulties which will be addressed deal with the development of an effective architecture of actuator with size compatible with typical robot end-effectors, their reliability and the demonstration of the industrial benefit in terms of compliance to inaccuracies, adaptability, safety and ability of offline programming and simulation. The involved end effectors will be self-controlled devices capable to perform a generic action even in case of variations in respect to the original mission, letting the programmability at high level of the system almost untouched.

Fig. 3. Multi-finger reconfigurable gripper [14]

3.3. Robotic perception for the environment, process and human

One of the core aspects of ODIN is the recognition, handling and assembly of parts with different shapes by stationary and mobile robots. The robots will be capable of recognizing and computing the pose of objects and humans [15] using local geometric features, which reduces the chain of uncertainty involved in the estimation process [16]. Individual perception technologies and equipment are already available on the market, but a significant advance will be achieved both in terms of hardware and software, with a new sensor and the integrating of latest advances in Machine Learning/AI into the perception chain (Fig. 4). The customization for achieving robust applications for each pilot will be one of the objectives of the project. In addition, strategies for higher accuracies in localization and actuation are necessary to be investigated, in order to successfully perform typical assembly tasks while the robot is on a moving platform. A new hardware iteration of the rc_visard [17] will be developed, aiming for higher flexibility in terms of baseline and connectivity options.

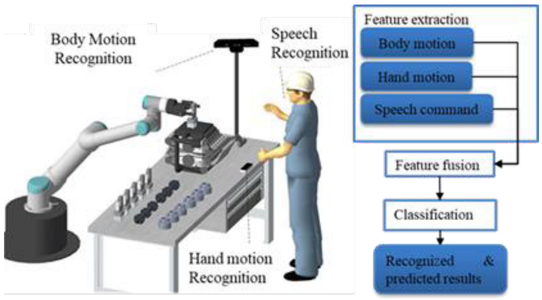

Fig. 4. Human perception approach

3.4. User friendly robot programming interfaces

The use of Skill Based Programming (SBP) framework enables the implementation of robotic applications sequencing configurable pre-programmed blocks (skills). Its demonstration indicated that it is very useful for easy and fast deployment of relatively simple operations such as pick and place, inspection, handling a device for performing a process, navigation, etc. The operations that, for the most part, can be generalized, can benefit of SBP approaches allowing a high degree of re-usability. The SBP techniques combined with CATIA based CAD Programming concept for skill configuration, allows the plant operators to take advantage of the intrinsic information that CAD models contains, for configuring new processes using pre-programmed skills. The use of an extended and well-known software that they are habituated to use, empowers the operators to easily and quickly adapt the existing robot programs, increasing thus the flexibility of the line. In addition to the CAD programming system, a new approach named Onsite Interactive Skill Programming (OISP) will be developed to exploit the skill programming system and configure the skills in continuous interaction with the robot.

3.5. Smart human side interfaces

Novel technologies for human machine interfaces in HRC will be also researched and tested in ODIN. The research will focus on AR/VR concepts both commercial but also experimental in nature. AR solutions for providing augmented information for the operator will be studied, such as assembly instructions, visualization of robot's current task and status, and alerts of potential hazards. A pilot cell will be implemented around the vision-based safety concepts based on digital light processing (DLP) projector and RGB/RGB-D cameras. The outside limit of robot's current work area will be projected as a dynamic line for human operator in order to increase awareness of the robot's current and upcoming position [18], [19]. Furthermore, the developed module will provide tools for implementing HMI based on projector technology, such as task instructions for the operator and projected virtual buttons for starting/stopping the robot, but also a two-hand control device in collaborative mode (Fig. 5). Also, focus will be given on VR approach for operator safety training and familiarization with HRC work cells by using a VR head-mounted display, such as HTC Vive, or any newer technology [20]. This will enhance safety in a shared workspace, as the operators will recognize safety concerns and instructions before they confront them in real devices. Additionally, the study will be expanded to provide dynamic safety instructions while the operator is doing the assembly task and gets informed if safety measures are violated and provide guidance on how to recover from the situation (Fig. 6).

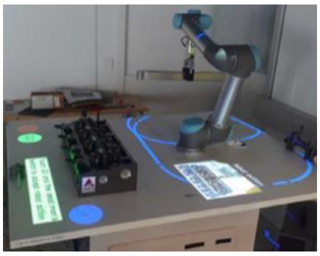

Fig. 5. Projected robot's workspace, operator instructions and HMI buttons [21]

Fig. 6. Virtual safety training in Hand Guiding demo [20]

4. Digital Component (DC)

The Digital Component (DC) is a virtual instance of the pilot implementing an accurate Digital Twin representation that allows the commissioning, validation and control of the actual pilot. This component targets on the application of Digital Simulation and Control tools to allow optimization and robust operation of the system in a modular way. The implementation of such tools is described in the following sections.

4.1. 3D simulation and virtual commissioning

The digitalization of the manufacturing industry has pushed the utilization of 3D simulation, which has been combined with other technologies such as VR/AR [22] and AI. Although, its extension to the validation, virtual commissioning and reconfiguration has been limited by the reusability of the digital information between the phases. A new perspective will be brought developing the digital models, including an open digital production resource description for information exchange, and the interfaces to integrate the hardware and software modules with Visual Components 4.0 (Fig. 7).

Fig. 7. Tools for 3D simulation and virtual commissioning [23]

The platform will provide open interfaces, which will allow developing a new simulation library with the involved digital models and extending the interfaces to integrate with the other software modules. This will reduce the engineering effort and delivery time of automation systems using virtual commissioning. The 3D simulation models, which provide the virtual and dynamic replica of the pilot, will be the base to create the digital twin using the information captured from sensors or factory information systems.

4.2. Digital Twin enabled through sensor data fusion

Over the last years, different digital twin methodologies have been proposed for industrial applications [24], although facing the common underlying issue of lack of real-world data. ODIN will focus on the deployment of a digital twin for the HRC system using sensor data fusion for fault prediction [25] and anti-collision. Based on the developed multimodal fusion system which utilizes a camera, a hand tracking module and a microphone for each worker, a digital twin of the HRC system (Fig. 8) will be designed to fuse data not only from the abovementioned sensors but also from robot controllers.

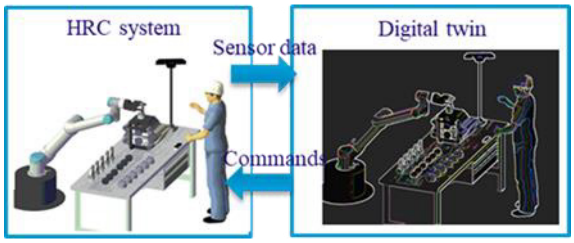

Fig. 8. Digital Twin enabled through sensor data fusion

Such data will be used for gathering the relative positions between humans and robots, as well as to recognize and predict HRC status and generate commands for the HRC system for safety operation and minimized downtime.

4.3. AI based task planning for work re-organization

The scope of the AI module for work re-organization will be to monitor the execution of the production plan and dynamically redistribute the workload to adapt the production [26] in real time. A digital world model will be created that will be continuously updated through the service network by all the perception components. Using this information and the status reporting of the autonomous robots, the workload balancing system will be able to generate alternative allocations for human and robots.

Fig. 9. Dynamic task planner

Models for representing human and robot shared tasks and the strategies to dispatch and coordinate the execution of these tasks will be used. The work will be focused on enabling the AI based, real time action and task planning module (Fig. 9), to use the perception from the resources and sensors in order to generate task allocations based on the shopfloor status.

5. Networked Component (NC)

The Networked Component (NC) is an integration architecture with open interfaces allowing the communication of all robotics hardware and control systems through safe and secure means. This will provide a standard and robust platform of integrating robotic technologies and linking them either to their OC and DC or other pilot instances running in the enterprise environment.

For the purposes of the large-scale pilots an integration platform that can easily compose a new line/cell from various individual components, ensure their communication and allow for production planning and resource allocation is required. A framework will be introduced to integrate a ROS Based HRC system that orchestrate HRC modules, monitor the execution and respond to shopfloor events. This relies on the OpenFlow architecture which will be customized to support further Industry 4.0 features such as connection to IoT Devices and support related protocols such as MQTT or REST interfaces. Openness will further be extended via integration with ROS Industrial and ROS2, further broadening the spectrum of potential connections. Finally, Open Flow will become Cloud enabled, designed to be ready to run in a Cloud environment.

6. Industrial Component (IC) Pilot Lines

The Industrial Component (IC) is a full-scale instance of the pilot, integrating hardware and software modules from the Open and Digital components and operations under an actual production environment. The aim is to validate at full scale and in real conditions the performance of the ODIN solution and its interoperability with OEM and Legacy systems. A description of the pilot cases and the deployment of ODIN solution is presented followed by a table of challenges and KPIs (Table 1).

6.1. Automotive pilot

Current State: The automotive pilot case of ODIN focuses on the engine assembly workshop. Different components such as motor block, gearbox, dashboard, etc. are added to the body at the assembly line. In the current assembly workstation, the main stakeholder is the human operator. Each operator is responsible to complete the different assembly tasks such as the connection of motor and gearbox, the assembly of additional parts and the quality assessment. The main challenge is the introduction of new vehicle difficulties such as the large quantity and diversity of parts as well as the work balancing to increase human ergonomic.

Future Vision: ODIN will investigate the introduction of collaborative robotic solutions in order to assist the human operator and undertake non-ergonomic tasks under a safe collaborative working environment. Furthermore, the use of autonomous mobile manipulators and reconfigurable robot tooling technologies will be able to handle a larger variety of products. Another core aspect is the integration of task planning methodologies in order to dynamically assign the different tasks between the different resources such as robots, human operators. Finally, the quality assessment will be optimized through the introduction of industrial vision-based solutions. The ODIN automotive setup is shown in Fig. 10.

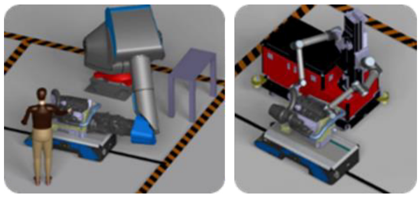

Fig. 10. ODIN setup for the automotive pilot

6.2. Aeronautics pilot line

Current State: The Aeronautics pilot case of ODIN (Fig. 11) focuses on the key operations of the assembly process of a Fan Cowl (FC), which is the component that serves as the external housing for the engines of the aircraft. The assembly process is very dynamic, depending on the demand and models and the layout of the workshop is continuously reconfigured. During the assembly process the FC is transported by two operators to many different locations in the workshop to perform concrete operations such as drilling. While most of the drills are done by a CNC, there are still some remaining drills that are done manually which consume a big amount of time. After each group of assembly operations, an inspection must follow to validate the correctness of the operations. Almost all of the inspections are done manually by human operators.

Future Vision: ODIN will automate the task of drilling, transport, and inspection of selected operations. One mobile manipulator will be able to adapt to the three different tasks by acquiring the tools required in each case. Due to the dynamic nature of the workshop layout configuration, the robot will be easy to be reconfigured. This will be possible thanks to the CAD programming module and the OISP module.

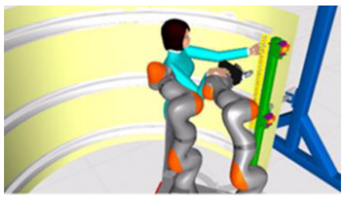

Fig. 11. ODIN setup for the aeronautics pilot

6.3. White goods pilot

Current State: The white goods pilot case of ODIN is based on a collaborative workstation installed in a Microwave Factory, able to mitigate the operator's high level of fatigue during the assembling of microwave transformers. The human operator is currently collaborating with a cobot requested to pick the microwave transformer from a pallet and to place it in the manual assembly zone. The transformer is then fixed by human operator with screwing tools before proceeding to further assembly workplaces. The main challenge is to improve the digital maturity level of the workstation in order to easily monitor the working parameters of the robotic application and enable the full potential of Industry 4.0 technologies.

Future Vision: ODIN will focus on creating the digital twin of the collaborative workstation. The digital twin will be deployed as a union of the real, digital and virtual world models. This will ensure an easier customization and deploy ability improvement of the current cobot solution, allowing integration of additional core technologies such as robotic units, individual sensing/ perception/ networking systems and facilitating the extension to other similar applications in other factories. ODIN will contribute to enhance the cobot autonomy into collaboration tasks, allowing the execution of non-sequential, non-pre-programmed, non-separated operations. Finally, another aspect will be the integration of task planning functionalities specifically focused on the needs of the pilot such as the investigation of the optimal layouts, safety devices, manipulation components and work cycle configurations.

Table 1. ODIN challenges and KPIs

Pilots	Challenges	KPIs
Automotive	Large quantity and diversity of parts – work balancing	Time to deploy and setup a mobile robot (-3hours)
Aeronautics	Various automation levels - operations' complexity	Automation level of a specific production task (100%)
White Goods	Flexible monitoring of the working parameters - enhance digital maturity	Planning & executing changes in production schedule – Time needed -20%

7. Conclusions and future work

This work has discussed the requirements and challenges for introducing novel robot-based production systems for immediate introduction at the shopfloor level. The enabling technologies were described as well as different pilot cases deriving from the automotive, aeronautics and white goods respectively. The technologies described in this paper are being implemented under the ODIN EC funded project and will be integrated in the three pilot cases during the project's lifecycle.

Future work will focus on the development of the ODIN technologies and their integration under real industrial environments based on the feedback provided from the end users. This will allow to accurately deploy the ODIN Components and measure the performance of the overall solution. Finally, any bottlenecks will be highlighted and will be taken under consideration towards the optimization of the involved technologies in terms of safe human-robot collaboration, process and human/robot perception, decision making & planning, digital twin and effective communication.

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References

[1] Chryssolouris G. Manufacturing systems: theory and practice. 2nd ed. New York: Springer; 2006.
[2] Liu M, Ma J, Lin L, Ge M, Wang Q, Liu C. Intelligent assembly system for mechanical products and key technology based on internet of things. J Intell Manuf 2017;28:271–99.
[3] Long J, Shelhamer E, Darrell T. Fully convolutional networks for semantic segmentation. 2015 IEEE Conference on Computer Vision and Pattern Recognition (CVPR),Boston,MA,USA: IEEE; 2015, p. 3431–40.
[4] Urcola P, Lorente M-T, Villarroel JL, Montano L. Robust Navigation and Seamless Localization for Carlike Robots in Indoor-outdoor Environments: Robust Navigation and Seamless Localization for Carlike Robots. J Field Robotics 2017;34:704–35.
[5] Michalos G, Makris S, Papakostas N, Mourtzis D, Chryssolouris G. Automotive assembly technologies review: challenges and outlook for a flexible and adaptive approach. CIRP Journal of Manufacturing Science and Technology 2010;2:81–91.
[6] Dianatfar M, Latokartano J, Lanz M. Review on existing VR/AR solutions in human–robot collaboration. Procedia CIRP2021;97:407–11.
[7] Gombolay M, Wilcox R, Diaz Artiles A, Yu F, Shah J. Towards Successful Coordination of Human and Robotic Work using Automated Scheduling Tools: An Initial Pilot Study. 2013.
[8] Brown E, Rodenberg N, Amend J, Mozeika A, Steltz E, Zakin MR, et al. Universal robotic gripper based on the jamming of granular material. Proceedings of the National Academy of Sciences 2010;107:18809–14.
[9] Wang XV, Wang L. Digital twin-based WEEE recycling, recovery and remanufacturing in the background of Industry 4.0. International Journal of Production Research 2019;57:3892–902.
[10] Kousi N, Gkournelos C, Aivaliotis S, Giannoulis C, Michalos G, Makris S. Digital twin for adaptation of robots' behavior in flexible robotic assembly lines. Procedia Manufacturing 2019;28:121–6.
[11] Makris S, Michalos G, Chryssolouris G. Virtual Commissioning of an Assembly Cell with Cooperating Robots. Advances in Decision Sciences 2012;2012:1–11.
[12] Hu SJ. Evolving Paradigms of Manufacturing: From Mass Production to Mass Customization and Personalization. Procedia CIRP 2013;7:3–8.
[13] Bøgh S, Hvilshøj M, Kristiansen M, Madsen O. Autonomous industrial mobile manipulation (AIMM): from research to industry. 2019.
[14] Spiliotopoulos J, Michalos G, Makris S. A Reconfigurable Gripper for Dexterous Manipulation in Flexible Assembly. Inventions 2018;3:4.
[15] Cherubini A, Passama R, Meline A, Crosnier A, Fraisse P. Multimodal control for human-robot cooperation. 2013 IEEE/RSJ International Conference on Intelligent Robots and Systems, p. 2202–7.
[16] Hillenbrand U. Pose Clustering From Stereo Data n.d.:10.
[17] rc_visard stereo camera system machine vision solution. Roboception n.d. https://roboception.com/en/rc_visard-en/
[18] Halme R-J, Lanz M, Kämäräinen J, Pieters R, Latokartano J, Hietanen A. Review of vision-based safety systems for human-robot collaboration. Procedia CIRP 2018;72:111–6.
[19] Hietanen A, Halme J, Latokartano J, Pieters R, Lanz M, Kämäräinen J. Depth-sensor-projector safety model for human-robot collaboration. 2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) Workshop on Robotic Co-workers 4.0: October 1-5, Madrid, Spain, 2018, IEEE; 2018.
[20] Dianatfar M, Latokartano J, Lanz M. Concept for Virtual Safety Training System for Human-Robot Collaboration. Procedia Manufacturing 2020;51:54–60
[21] Hietanen A, Pieters R, Lanz M, Latokartano J, Kämäräinen J-K. AR-based interaction for human-robot collaborative manufacturing. Robotics and Computer-Integrated Manufacturing 2020;63:101891.
[22] Andersson N, Argyrou A, Nägele F, Ubis F, Campos UE, Zarate MO de, et al. AR-Enhanced Human-Robot-Interaction - Methodologies, Algorithms, Tools. Procedia CIRP 2016;44:193–8.
[23] Visual Components - 3D manufacturing simulation software. Visual Components n.d. https://www.visualcomponents.com/
[24] Kousi N, Gkournelos C, Aivaliotis S, Lotsaris K, Bavelos AC, Baris P, et al. Digital Twin for Designing and Reconfiguring Human–Robot Collaborative Assembly Lines. Applied Sciences 2021;11:4620.
[25] Wang Y, Tao F, Zhang M, Wang L, Zuo Y. Digital twin enhanced fault prediction for the autoclave with insufficient data. Journal of Manufacturing Systems 2021;60:350–9.
[26] Michalos G, Sipsas P, Makris S, Chryssolouris G. Decision making logic for flexible assembly lines reconfiguration. Robotics and Computer-Integrated Manufacturing 2016;37:233–50