D3.1. Demonstrator Introduction

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PP	Restricted to other programme participants (incl. Commission Services)	
RE	Restricted to a group specified by the consortium (incl. Commission Services)	
CO	Confidential, only for the members of the consortium (incl. Commission Services)	

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Acronyms and abbreviations

3D	three dimensional
AR	Augmented Reality
BIM	Building Information Model
GUI	Graphical User Interface
HMI	Human Machine interface
HRC	Human Robot Collaboration
HRI	Human Robot Interaction
HW	hardware
IIoT	Industrial Internet of Things
IoT	Internet of Things
ISO	International Standardistaion Organisation
MS	Microsoft
OCR	Optical character recognition
PLC	Programmable Logic controller
ROS	Robot Operation System
SW	Software
TS	Technical Specification
UFP	User-friendly programming
UWB	Ultra Wide Band
VR	Virtual Reality
WSN	Wireless Sensor Network

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1 Introduction

The TRINITY consortium has been developing several demonstrators in different areas of robotics and industrial IoT, which we identified as the most promising to advance agile production but has not yet been widely applied in industrial applications. The aim of the demonstrators is to provide example implementations that serve as a guideline to manufacturing companies for how to introduce new advanced robotics technologies in their production processes. The following demonstrators are currently under development:

- Use case demonstration 1: Collaborative assembly with vision-based safety system
- Use case demonstration 2: Collaborative disassembly with augmented reality interaction
- Use case demonstration 3: Collaborative robotics in large scale assembly, material handling and processing
- Use case demonstration 4: Integrating digital context (e.g. BIM) to the digital twin with AR/VR of the robotized production
- Use case demonstration 5: Wire arc additive manufacturing with industrial robots
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- Use case demonstration 14: Virtualization of a robot cell with a real controller
- Use case demonstration 15: IIoT Robustness Simulation
- Use case demonstration 16: Flexible automation for agile production
- Use case demonstration 17: Artificial intelligence based stereo vision system for object detection, recognition, classification and pick-up by a robotic arm
- Use case demonstration 18: Rapid development, testing and validation of large scale wireless sensor networks for production environment

Compared to the proposal, there is one additional demonstrator focusing on large scale wireless sensor networks for production environment (demonstrator no. 18). Some of the other demonstrators have been revised to better address the main theme of the project, i.e. advancement of agile production through robotics and related technologies.

The above demonstrators typically involve several tightly integrated software and hardware components that are difficult to use as complete systems. The developers have therefore extracted from the demonstrators several largely self-sufficient software and hardware modules, which are easier to use and

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can be offered to industrial partners for use in their applications without raising many complex support issues.

The demonstrators and modules presented in this document serve as reference implementations for two rounds of open calls for application experiments, where companies with agile production needs and sound business plans will be supported by TRINITY DIHs to advance their manufacturing processes.

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2 Internal Demonstrators

We defined 18 internal use case demonstrations to demonstrate novel robotic and related technologies that have the potential to increase the agility of production processes in industrially relevant environments (TRL 5 and above).

2.1 Use-case demonstration 1: Collaborative assembly with vision-based safety system

Demonstrator owner is Tampere University (TAU). The main goal is to provide safe and intuitive robotic interface for human-robot collaboration.

2.1.1 Description

Human-robot interaction for collaborative manufacturing requires special attention for HRI safety systems since robots and payloads can lead to potentially dangerous situations. We introduce a safety model that creates a dynamic 3D map of the working environment and at the same time ensures minimum safety distance between the human and robot. If human comes too close to the robot, a safety violation is detected and the robot is immediately stopped. The model is created, updated and monitored using a single depth sensor. In addition, a projector is installed on top of the work environment and robot safety zone and virtual user interface components are projected onto a flat surface to increase the human awareness during the task, see Figure 1. The system is demonstrated in a collaborative diesel engine task.

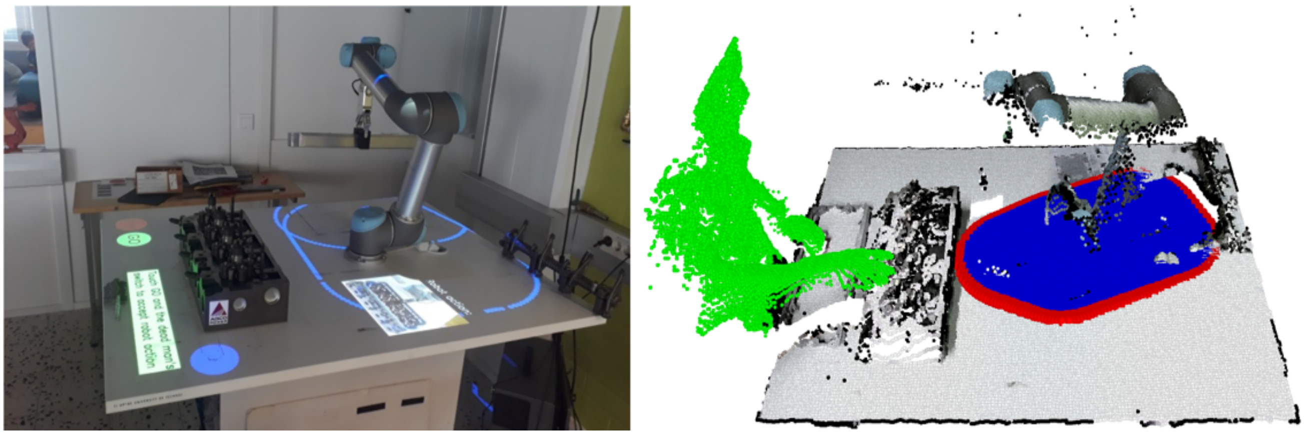

Figure 1: Robotic interface for safe HRC. Virtual user interface projected on the shared workspace (left) and safety model that is used to ensure safe interaction between human and robot (right).

The used hardware components are Universal Robots (UR5), OnRobot RG2 gripper, Kinect, standard LCD projector. The main software components used are Linux and Robot Operating System (ROS). The relevant standards and specifications addressed in the demo are ISO/TS 15066:2016, ISO 10218-1/2.

2.1.2 Value added from Safety zone visualisation

Experiments with the system has shown that the safety system can be used in HRC to ensure the safety of the co-worker and improve the performance in the terms of task execution time. The main reason for the

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improvements is the fact that the safety model allows the human and robot to work in parallel in a shared workspace.

2.2 Use-case demonstration 2: Collaborative disassembly with augmented reality interaction

Demonstrator owner is Tampere University (TAU). The main goal is to provide safe and intuitive robotic interface for multimachine work environments, where the human worker operates together with traditional industrial robots (payload up to 50kg) and mobile robots. The safety is realized using external vision system and AR-based technology, illustrated in Figure 2.

2.2.1 Description

Figure 2: Use of augmented reality in multimachine work environment. Diesel assembly task and multiple industrial robotic arms and mobile robot (left), state-of-the-art Head-Mounted Display (middle), and holographic information visualized on top of the work environment

Industrial manufacturing is going through a process of change toward flexible and intelligent manufacturing, the so called Industry 4.0. Human-robot collaboration will have more prevalent role in this process and this will require special care for human safety and interaction as the existing industrial practices are based on the principle that human operator and a robot have separated workspaces. We introduce a robotic application consisting of multiple robot agents that share a common task with a human co-worker. The introduced system has an external vision system that can scan products and recognize their type and pose (position and orientation) in the shared workspace. The cell control system will make task allocation between robots and the operator. The operator can see the instructions regarding the disassembly and safety related information using a wearable AR (Microsoft HoloLens). He/she communicates with the system using hand gestures, speech, and camera-projector based technology. Multi-camera system monitors the workspace for safety violations and halts the robot or reduces its speed. The system is demonstrated in a disassembly of an industrial product.

The used hardware components are ABB IRB4600, Schunk gripper with 3D printed fingers, Kinect, standard LCD projector, Safety Eye (for secondary safety) and Microsoft HoloLens. The main software components used are Visual Components (offline programming, calibration and safety inspection during preparatory work), Linux and Robot Operating System (ROS). The relevant standards and specifications addressed here are ISO/TS 15066:2016, ISO 10218-1/2.

2.2.2 Value Added from utilizing AR in HRC.

The value added comes from utilizing mixed reality in human robot collaboration. Algorithms and modules that enable safe and interactive HRC in industrial environments can be realized and tested with AR-based technology.

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2.3 Use-case demonstration 3: Collaborative robotics in large scale assembly, material handling and processing

Demonstration is owned by Centria University of Applied Sciences (Centria). The main goal is 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.

Figure 3 Element handling with large robot

Figure 4 Wooden elements as a case product

2.3.1 Description

Demonstration of agile industrial robotization of a large-scale material handling, processing or prefabrication where robots and people will process components collaboratively (Figure 3 and Figure 4). The working zone will be monitored dynamically and provided to the worker and robot together with the task plans and situation aware information. In the use case different multimodal human-computer interaction methods are evaluated.

The used hardware components are ABB and KUKA robots, Universal Robots (UR3/10), Robotiq gripper, Pilz Safety Eye, 3D Kinect, RF tracking and local positioning systems, LIDARs, PhotoXi 3D Scanner, Sick S300 safety scanner. The main software components used are Visual Components, ABB Robot Studio, RoboDK and AUTOMAPPPS. Open source software ROS and CloudCompare. The relevant standards and specifications addressed here are ISO/TS 15066:2016, ISO 10218-1/2.

2.3.2 Value Added from HRC in heavy loads handling

The demonstration provides a showcase for human and industrial robot collaboration in industrially relevant environment, and aims to contribute to the development of more flexible and dynamic 3D safety applications.

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2.4 Use-case demonstration 4: Integrating digital context (e.g. BIM) to the digital twin with AR/VR of the robotized production

This demonstration is owned by Centria University of Applied Sciences. 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.

2.4.1 Description

Demonstrate how companies carrying out prefabrication can utilize robotized manufacturing to get their production more agile by integrating BIM, digital twin and VR/AR technology. They can utilize these agile concepts for more flexible monitoring, operational support, training, safety and maintenance purposes of the production cell (Figure 5).

The used hardware components are ABB/KUKA/UR robots, MS HoloLens, HTC Vive, 3D Kinect, LIDARs, NDI Optotrack, Leica long range scanner, SICK encoders. The main software components used are Dassault 3DExperience, Visual Components, ABB Robot Studio and RoboDK. Open source software: Unity, Vuforia, Blender, ROS and Linux). The relevant specification addressed here is mainly ISO/TS 15066:2016.

Figure 5 Merged models

2.4.2 Value Added utilizing merged digital content

The value added from this demonstration is the showcase on how to merge different digital contents over the SW boundaries and cross-domain. In this demonstration a combination of digital twins, Building Information Model (BIM) and AR/VR technology for collaborative robotics in industrial environments as used for a better human-robot interaction, and dynamic 3D safety

2.5 Use-case demonstration 5: Wire arc additive manufacturing with industrial robots

This demonstration is owned by Arctic University of Norway (UiT). The main goal of this demonstration is to increase production rate with additive manufacturing of metal parts (Figure 7).

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2.5.1 Description

The industrial robot has an important role in the automation of the manufacturing industry and has considerably contributed to the improvement of profitability and working environment. However, there are still many tasks in industry that require heavy work, e.g. in additive manufacturing based on welding.

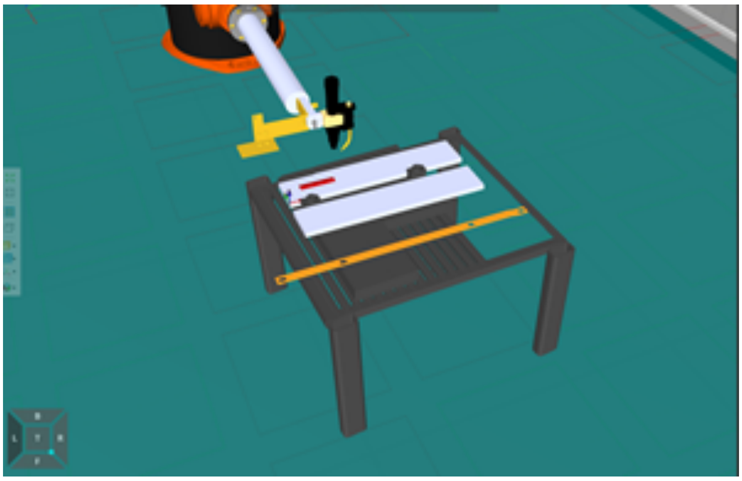

Figure 6: Task planning in 3D simulation

Figure 7: Some of the performed work

The used hardware components are KUKA KR30-3, Fronius MagicWave 5000. The main software components used are Open source software e.g. ROS and commercial simulation and off-line programming SW Visual Components (Figure 6). The relevant standards and specifications addressed here are ISO 10303, ISO 6983, NS-EN 1011-1:2009, ROS-I.

2.5.2 Value Added from enhanced AM

This use-case represents a new conceptual solution for additive manufacturing. The solutions contain the required level of intelligence and flexibility to apply robotized TIG welding in manufacturing and construction. The system and setup will be assessed against different Cybersecurity vulnerabilities identified, issues coming out of a quick scan self test, and other known challenges.

2.6 Use-case demonstration 6: Production flow simulation and supervision

This demonstration is owned by Arctic University of Norway (UiT). 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.

2.6.1 Description

Factories of the future will face increasing demands for a non-stop production, accompanied with high flexibility and safety requirements. This implies an important future market for instant services dealing with support, error diagnostics and reconfiguration of industrial robot systems. These advances can be achieved by utilizing IoT in every stage of the production process in a factory. Based on the collected data, decisions can be made even from distant locations.

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The used hardware components are Raspberry Pi, PLCs, Industrial robots, Figure 8. The main software components used are Open source software (ROS, MoveIt, Gazebo) and commercial (FlexGUI, VisualComponents) illustrated in Figure 9. The relevant standard addressed here is mainly the ISO 10303.

Figure 8: Factory setup

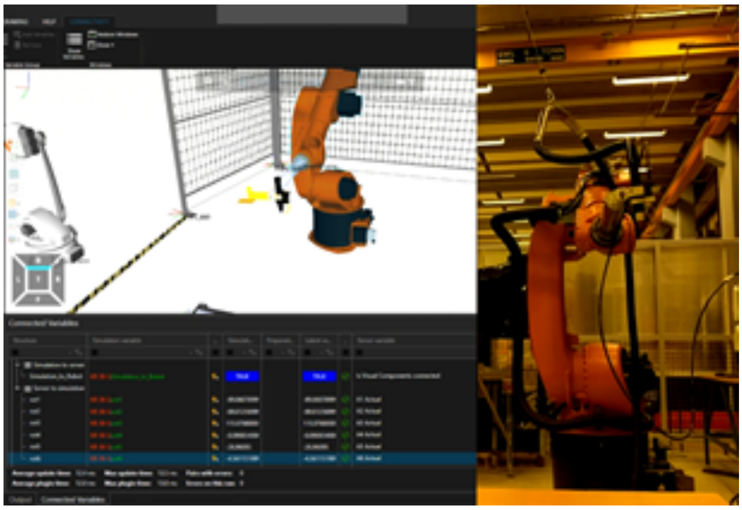

Figure 9: Supervision

2.6.2 Value Added from production flow simulation and supervision

This use-case demonstrates the usability of IoT (PLCs, robot cells, sensors, actuators) in a production flow, where data is continuously monitored, collected and actions can be carried out through a simulation environment (e.g. Gazebo) or automatically. Transmission of data amongst various components, increases the number of specific security issues that could be derive. The data is distributed with ROS components.

2.7 Use-case demonstration 7: Robot workcell reconfiguration

This demonstration is owned by Jožef Stefan Institute (JSI). 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.

2.7.1 Description

To enable partially autonomous reconfiguration of robot workcells, we equipped our workcell with innovative reconfigurable hardware elements with passive (non-actuated) degrees of freedom such as passively reconfigurable fixtures, passive linear units for relocation of robots, passively reconfigurable rotary tables, etc. The developed passive components are equipped with pneumatic braking systems. When the brakes are released, the robot can move the reconfigurable components along their passive degrees of freedom and reconfigure the workcell. Such solutions are relatively inexpensive compared to solutions with actuators but can still be reconfigured without human intervention as robots are used to move the passive elements.

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The software to control the workcell, including reconfiguration processes, is ROS-based. It provides the developed workcell with modularity necessary to exchange the workcell's software and hardware components as required when switching from one production tasks to another. Software tools to support the reconfiguration of the available passive hardware by robots will be implemented in this demonstrator. These tools will provide automatic computation of optimal postures of fixtures and workpieces, taking into accounts the constraints imposed by the workcell, illustrated in Figure 10.

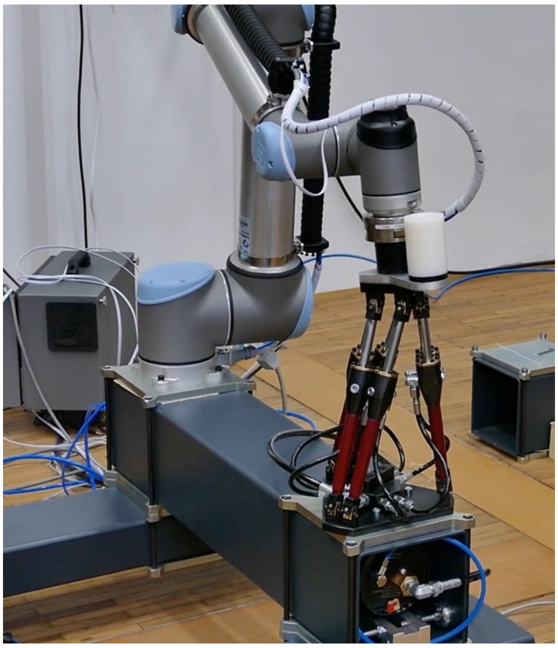

Figure 10: Robot-supported reconfiguration of a passive fixture.

The used hardware components are 2 Universal Robots UR10, DESTACO tool changers, reconfigurable passive hardware (linear guides, hexapods, turntables), 3-D printing of gripper fingers and fixtures. The main software components used are ROS (Robot Operating System), MATLAB (optional). The relevant standards and specifications addressed here are ISO/TS 15066:2016, ISO 10218-1/2.

2.7.2 Value-added from robot workcell reconfiguration

By applying the proposed passively reconfigurable elements and methods to automatically compute optimal workcell configurations, the time needed to change production from one product to another and the amount of the necessary human intervention will be reduced. Compared to previous implementations, the process of computing optimal configuration will be automated. This functionality will be demonstrated in an industrially relevant use case.

2.8 Use-case demonstration 8: Efficient programming of robot tasks by human demonstration

This demonstration is owned by Jožef Stefan Institute (JSI). Traditional systems for programming of industrial robots are still quite complex and rely on users possessing extensive knowledge about advanced robotics concepts. End-users therefore often cannot program their robots without the help of system integrators, which prolongs the required programming time and increases the price of robot applications. In this demonstrator, we address these 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, e.g. automated robot assembly.

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2.8.1 Description

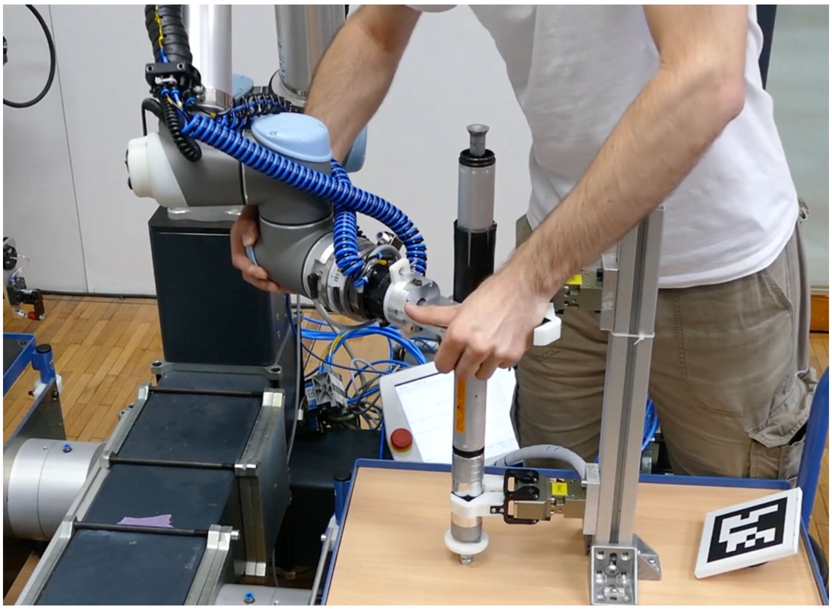
Figure 11: Programming of point-to-point movements

Programming by demonstration based on kinesthetic teaching can be implemented on robots that allow users to guide them by hand through the desired movements and robot configurations (see Figure 11). To realize an effective robot programming system based on kinesthetic teaching (guidance), we developed a user-friendly button interface as a front-end to control different robot modes and save the gathered data. The back-end is implemented as a ROS-based database, which is available across all modules of a robot workcell. The kinesthetic teaching can be applied to effectively program new robot skills and calibrate the workcell by guiding the robot arm through the desired movements. The resulting data and programs can be used to instantiate robot task sequences controlled by ROS-based hierarchical state machines specified in SMACH. In addition, we will integrate into the system advanced robot learning technologies, which will enable the robot to automatically improve its performance through successive repetitions of task execution. The effectiveness of the proposed system will be demonstrated by programming industrially relevant assembly tasks.

The used hardware components are a Universal Robot UR10 (or other robots that enable gravity compensation, e.g. Kuka LWR, Franka Emika Panda, etc.), button interface module, PC workstation. The main software components used are ROS (Robot Operating System), MATLAB (optional). The relevant standards and specifications addressed here are ISO/TS 15066:2016, ISO 10218-1/2.

2.8.2 Value-added from programming of robot tasks by human demonstration

The value added from this demonstration is that the operators without extensive expert knowledge in robotics will be able to efficiently program and deploy new robot manufacturing applications.

2.9 Use-case demonstration 9: Dynamic task planning & work re-organization

The demonstration is owned by LMS – University of Patras. This internal use case's 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. The main target group of the developed technology is SMEs that need novel solutions for optimizing their production, while automating the design process. This use case falls into the 29.3 Nace code describing "Manufacture of parts and accessories for motor vehicles" related activities.

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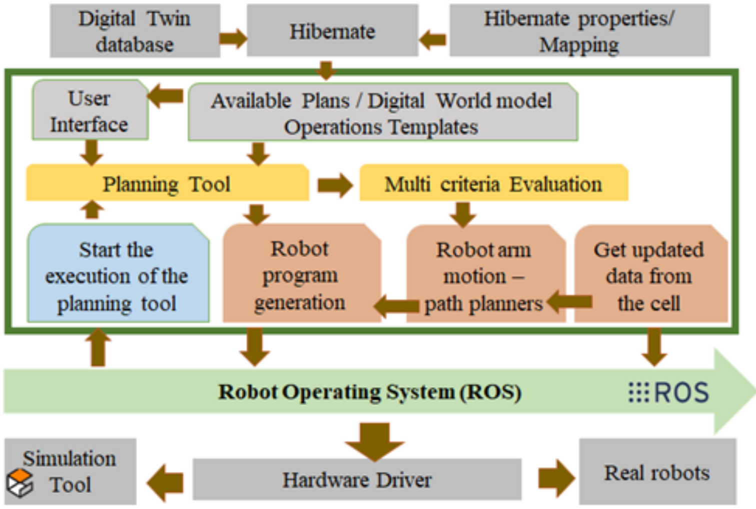

Figure 12: Decision-making framework

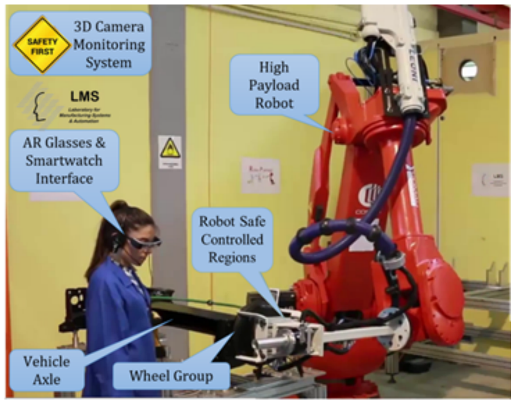

Figure 13: HRC assembly cell

2.9.1 Description

To this direction, is demonstrated an intelligent decision-making framework. The implemented framework generates and evaluates alternatives for task allocation and rough motion planning of human and robot operations, using information and data extracted from simulations (Figure 12 and Figure 13). The evaluation of the generated alternatives is based on multi-criteria decision-making modules, integrating 3D graphical representation, simulation and embedded motion planning (Figure 14).

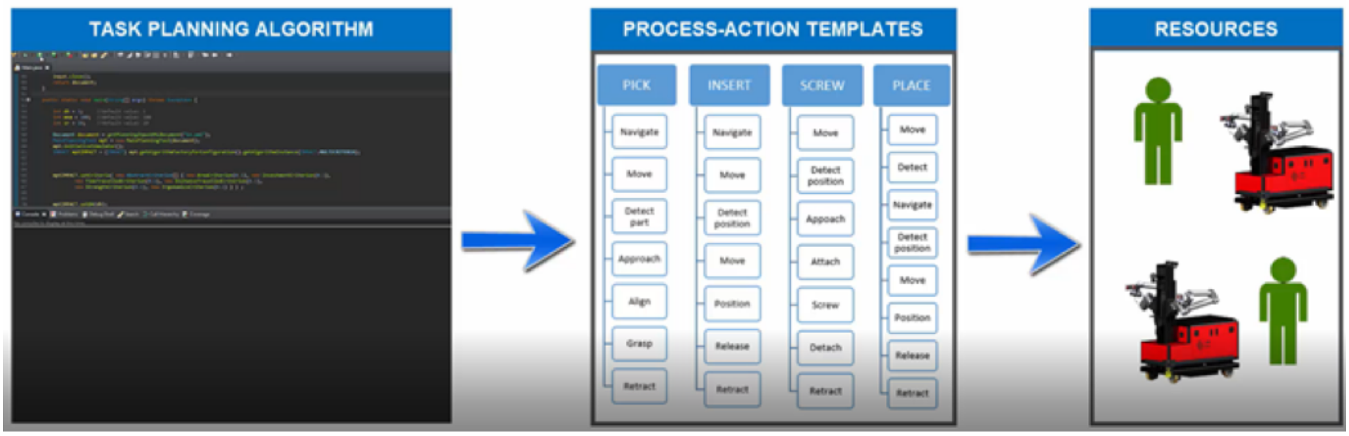

Figure 14: Task planning process

The used hardware components are a high performance computer. The main software components used are Open source software (ROS), Siemens - Process Simulate. The relevant standards and specifications addressed here are Open source software (ROS), Siemens - Process Simulate.

2.9.2 Value-added from dynamic task planning and work re-organization

The design of tasks and workplaces is a time-consuming process needing the feedback of designers, process engineers, system integrators, etc. The proposed solution will address this issue by gathering in one tool all

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this knowledge and providing feedback to the human within a short time frame (some minutes instead of 1-month work), making the production system much more flexible and reconfigurable.

2.10 Use-case demonstration 10: HRI framework for operator support application in human robot collaborative operations

This demonstration is owned by LMS – University of Patras. In many industries, the assembly process is mainly performed by human resources. This is due to the fact that assembly operations usually require humanlike sensitivity. Industries need to increase quality levels in terms of precision and repeatability, to reduce throughput time in assembly stations, to enable traceability of the performed operations and to reduce operators' ergonomic stress (e.g. by reducing the applied physical strength). This can be done with the introduction of automation systems to the assembly lines. 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. The main target group of the developed technology is SMEs that are interested in exploiting the synergy effect of humans and robots in the assembly process. This use case falls into the 29.3 Nace code describing "Manufacture of parts and accessories for motor vehicles" related activities.

2.10.1 Description

To this direction, is demonstrated an Augmented Reality (AR) application. This application provides to the human operators:

1. Assembly instructions
2. Robot behavior information for increasing safety awareness
3. Safe working volumes
4. Production status information

Also, interfaces on smart wearable devices enable the easy and direct human robot interaction while the HRC execution is orchestrated and monitored through a service – based controller (see Figure 15).

The used hardware components are Industrial robots, augmented reality glasses, and a smart watch. The main software components used are Open source software: ROS, RosBridge, ROS Java, Unity, and Vuforia. The relevant standards and specifications addressed here are ISO/TS 15066:2016, ISO 10218-1/2.

Figure 15: AR-based application: the operator's field of view

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2.10.2 Value-added from HRI framework

The human awareness about the tasks to be executed is based on the use of printed papers with instructions and there is no live monitoring of the status as well as cognition capabilities. Within this demonstration the aspect of awareness will be increased. In addition, unexperienced operators can be allocated to work in HRC cells and execute new processes without extended training requirements. Thus, the production system becomes more agile on re-allocating human resources according to the production needs. This increases the system's reconfigurability, as it enables a more efficient re-allocation of the human resources according to the production needs.

2.11 Use-case demonstration 11: Robotized serving of automated warehouse

This demonstration is owned by Budapest University of Technology and Economics (BME). The goal is to demonstrate the feasibility of using mobile robots in intralogistics. The potential users are SMEs who are dealing with smart assembly involving mobile robots.

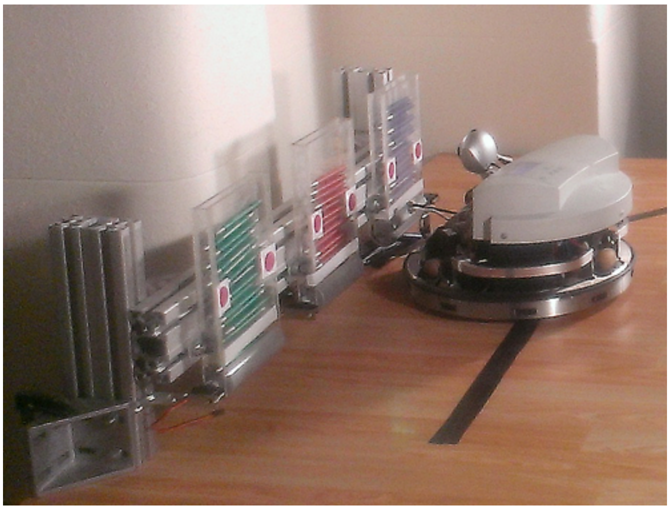

Figure 16: Approaching the target

Figure 17: Line following with a mobile robot

2.11.1 Description

The demonstration is based on a mobile robot equipped with three omni-wheels. The automated warehouse in the demonstration is a pen wending machine operated by a microcontroller. The wending machine has 3 slots for holding 3 differently colored pens and serving 1 pen at a time. The robot recognizes the task by a label coded card shown to its camera using optical character recognition (see Figure 16). The main hardware of the demonstration is the mobile robot platform Festo Robotino®. The complete robot control software was implemented using National Instruments LabVIEW™ graphical programming language.

The used hardware components are PC with Wi-Fi connection capability, Festo Robotino® v2 with factory standard accessories, custom built pen wending machine, and wooden floor. The main software components used are LabVIEW™ graphical programming language version 2018 or higher.

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2.11.2 Value-added from robotized servicing

Possible benefits of the demonstration are applications with mobile robots, optical character recognition, target detection and controlled maneuvering, as well as path tracking without compromising safety (see Figure 17).

2.12 Use-case demonstration 12: User-friendly human-robot collaborative tasks programming

This demonstration is owned by Flanders Make. The following use case introduces a new method of programming robotic applications which is intuitive, user-friendly and requires no prior robot programming expertise. Intuitive features of programming such as by using HMI, speech, and teaching by demonstration will allow the creation/modification of robotic applications in a cost and time effective manner. This use case will target SMEs and large-scale industries requiring flexible assembly solutions.

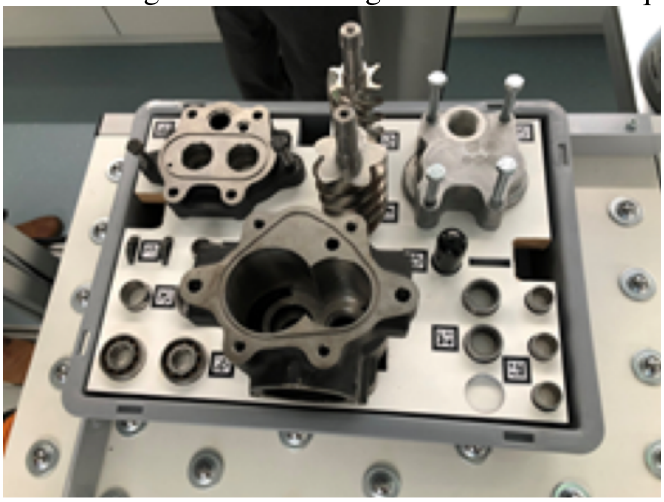

Figure 18 Air compressor components tray

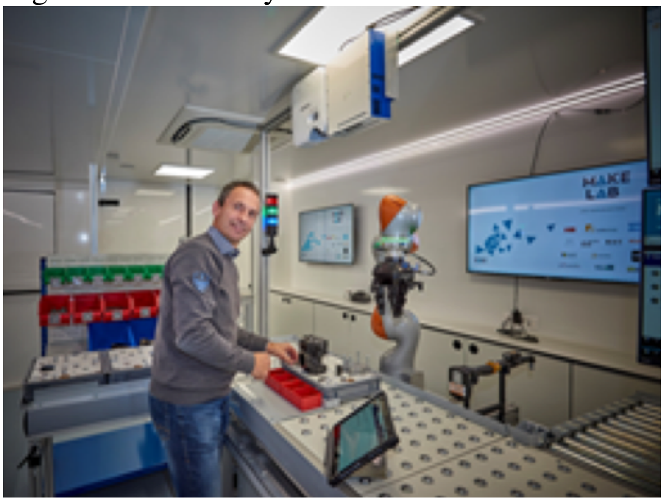

Figure 19 Operator collaborating with the robot

2.12.1 Description

In contrary to classical robot programming methods, which requires reasonable robot programming experience in order to create/modify the robotic application, the user-friendly programming (UFP) module will demonstrate that assembly steps can be taught by an operator in an intuitive manner either by using HMI, speech, or teaching by demonstration in order to create a new application or modify the existing application to adapt the product variation in assembly. Operator can teach new trajectories to the robot by using teaching by demonstration to make assembly more effective. Further modification can be done in a similar way to better achieve the desired goal. HRC compatible, lightweight KUKA LBR iiwa robot equipped with 3-finger adaptive Robotiq gripper assisted by vision sensor will be used for the demonstration. The system will carry out the assembly of an air compressor (**Error! Reference source not found.**) which involves complex handling and manipulation tasks during the process, Figure 19. Complete application for air compressor assembly can be made by piecing together easily programmable subtasks/skills without need of complex coding which can be further modified to better adapt the needs. Figure 20 provides a glimpse of the GUI. With UFP, an efficient robot programming method in contrast to classical robot programming methods has been introduced. With this approach, a significant reduction of programming time can be achieved without prior need for robot programming experience. Furthermore, the

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existing robot applications can be easily adapted to the production needs in case a variation is introduced in a given assembly process.

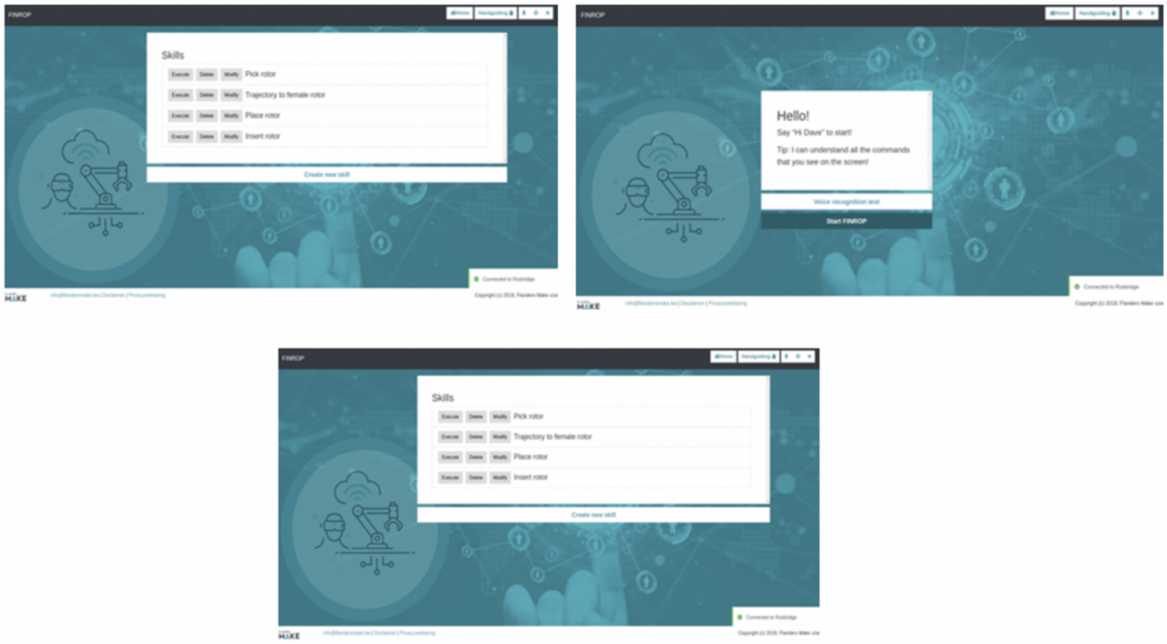

Figure 20 User-friendly programming home screen (left). Adding skills for the application (right). Modifying skills (bottom)

The used hardware components are Kuka LBR iiwa, Robotiq gripper, air compressor components (workpiece), vision system. The main software components used are ROS/ROS2, Automapps, Nuance/Google, Halcon, Sunrise OS (Java). The relevant standards and specifications addressed here are ISO/TS 15066:2016, ISO 10218-1/2, ISA-95.

2.12.2 Value-added from collaborative tasks programming

Large reduction in programming time (vendor-independent) that leads to cost saving. The required operator training to create robot applications is reduced. The functionalities are presented as add-on module that gives intuitive programming ability to any robot.

2.13 Use-case demonstration 13: Deployment of mobile robots in collaborative work cell for assembly of product variants

This demonstration is owned by Flanders Make. 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. The potential application sector for such use case is foreseen to be in SMEs and large-scale companies that need flexible mobile robotic solutions.

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2.13.1 Description

This demonstration will showcase the capabilities of mobile manipulators in work places shared by humans. The mobile manipulator will be able to assist in logistics of different tasks being performed in the work cell by navigating to the pick points of different parts, picking and kitting, and dropping the parts to the designated drop points, Figure 21. Accurate localization of the robot in an indoor working environment is fundamental for precise navigation and manipulation.
The platform which will be used for the demonstration is KUKA KMR mobile robot equipped with KUKA LBR iiwa collaborative manipulator. KMR robot localizes itself by fusing sensory information from the wheel encoders and laser scanners alongside sensor fusion of UWB tags and beacons. Mobile manipulator movements are planned with obstacle avoidance by solving a numeric optimization problem which takes into account of a continuously updated digital representation of the environment.

Figure 21: (left) Representation of KUKA KMR docking at the workstation. (right) KUKA KMR with LBR iiwa.

In the beginning, the robot needs to localize itself accurately using sensor fusion techniques in the indoor working environment during its motions. Next, the mobile manipulator movements are planned, avoiding obstacles, by solving a numerical optimization problem which takes into account a continuously updated digital representation of the environment. KMR robot will perform kitting of air compressor components in a collaborative work cell. This application will demonstrate the ability of the mobile robot to precisely navigate and accurately dock at the racks, which are located at different positions in the work cell, in order to pick the compressor parts. After completing the kitting from different locations with different required parts needed for air compressor assembly, the KMR robot will bring it back to the assembly workstation.

Mobile manipulators collaborating in such use cases will allow the deployment of robotics in manufacturing operations with unlimited reach. The onboard and external sensing systems with ability of mobile manipulation enable the realization of autonomous and agile manufacturing that can cope with variability in the manufacturing processes and provide extensive flexibility in assembly operations.

The used hardware components are Kuka KMR, Ultra Wide Band tags, Ultra Wide Band beacons. The main software components used are ROS/ROS2, Sunrise OS, OpenCV. The relevant standards and specifications addressed here are ISO/TS 15066:2016.

2.13.2 Value-added from mobile robots in collaborative work cell

Mobile collaborative robots allow to deploy robotics in manufacturing operations with unlimited reach. Their on-board and external sensing systems allow to realize autonomous and agile manufacturing that can cope with variability.

2.14 Use-case demonstration 14: Virtualization of a robot cell with a real controller

This demonstration is owned by Fastems. 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.

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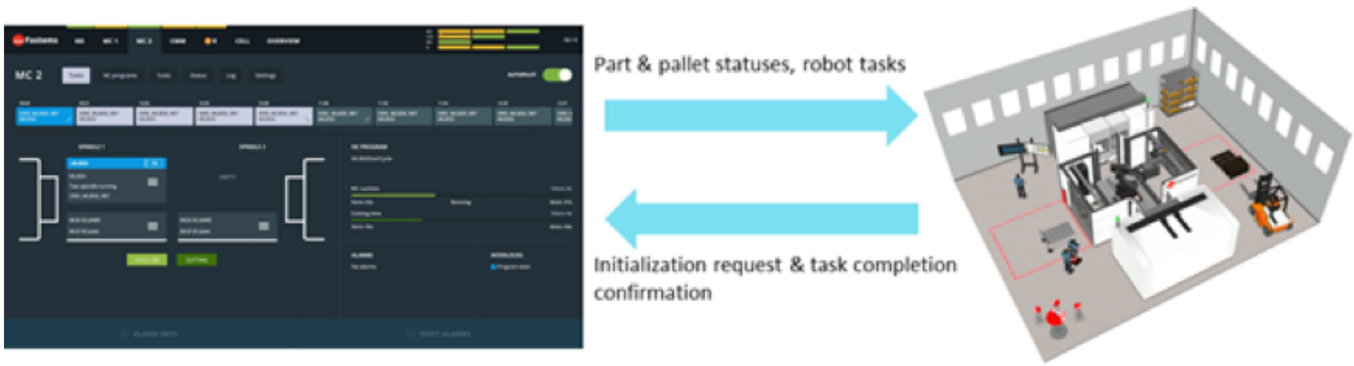

Figure 22: The control software user interface (left) and the virtual model (right)

2.14.1 Description

The demonstrator focuses on the control of simulated manufacturing hardware using a real controller. The simulated hardware is represented in a real-time 3D-environment, which can be used for demonstrating actual system functionality, training employees, virtual commissioning and testing production operations for new parts. These activities can be done before the system even exists or after commissioning, when they can be done without disturbing the ongoing production. Since the control software used is identical to the real-world control software, all master data created with the virtual system can be transferred to the real one.

The hardware and software involved in this demonstrator are shown below in Figure 23. The main hardware consists of two PCs that are connected with an Ethernet-cable and communicate with each other through the WebSocket-protocol.

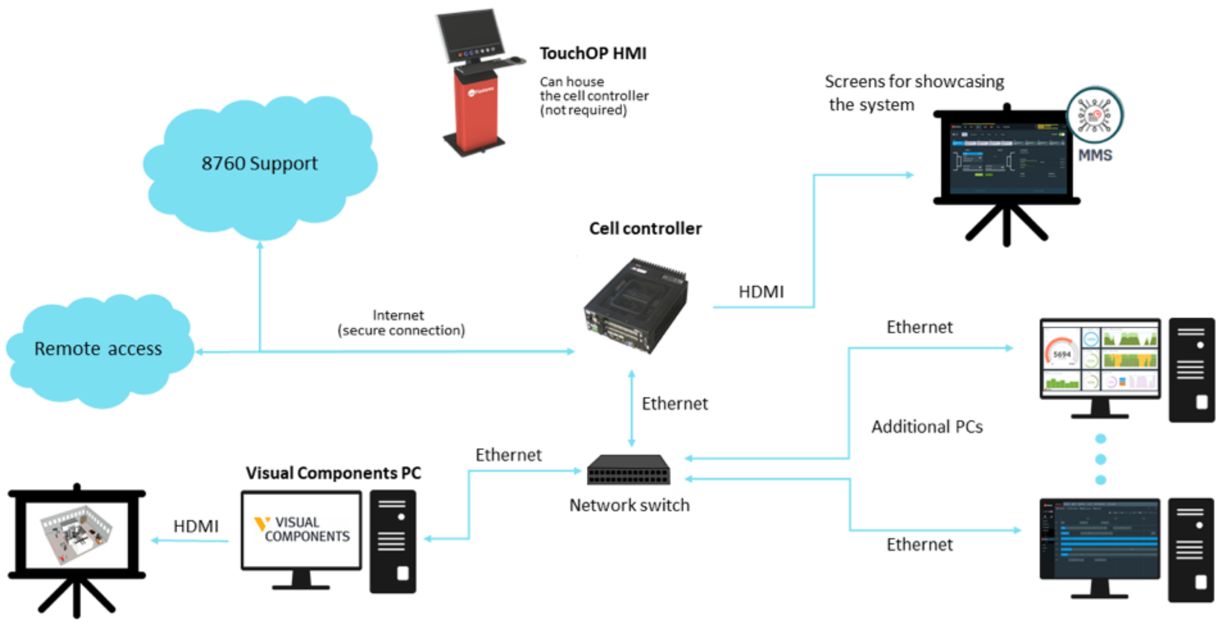

Figure 23: Software and hardware components of the module

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The Fastems cell controller is an industrial PC that is used to host the MMS (Manufacturing Management Software). It is identical to the one used to control real manufacturing hardware. The cell controller can also be housed inside a TouchOP -device which provides the user with a screen, keyboard and mouse that can be used to interact with the MMS user interface. Otherwise, a separate set of these peripherals is required. The cell controller includes a Fastems specific connectivity solution which allows the Fastems 8760 Support and user to connect to the system remotely. The sole purpose of the Visual Components PC is to run the virtual model and after the model is configured and running it doesn't require any additional user inputs. Therefore, only a screen is required for this PC. A virtual reality headset can be attached to allow the user to walk around the virtual system. There are no specific system requirements for the PC, but it must meet the minimum requirements for running Visual Components 4.1. Additionally, multiple PCs and screens can be connected to the system to view and interact with the MMS user interface. These PCs can be used to add and edit master data, view and create production orders, import NC-programs, view the key performance indicators (KPIs) etc. locally or remotely. The screens allow the user to display the virtual model or e.g. system KPIs to a larger audience.

Both PCs are run on the Windows 10 operating system. The version of the control software is MMS 7.2 and the Visual Components version is 4.1. The relevant standards and specifications addressed here are WebSocket, JSON and Python 2.7.

2.14.2 Value-added from cell controller virtualisation

The value added comes from

1) Training employees: Since the MMS is identical to the real-world one employees can be trained in a safe and realistic way with this module. They can interact with the MMS user interface and at the same time see how the robot cell behaves. They can even walk around the cell with the help of a VR-headset to understand the scale and possible hazards of the robot cell. This can be done before the real system is delivered which makes the production ramp-up faster and safer.
2) Demonstrating system functionality: The detailed virtual model enables the user to use the visualization capabilities to demonstrate and teach the basic principles of agile manufacturing cells. The real-time visualization makes it easier to understand the fundamental concepts of the cell.
3) Testing new parts: New parts can be trialed in the virtual system before introducing them to the real one. This means that the user can import the CAD-model of the part into the virtual cell to make sure that the clearances are large enough and that no other issues appear. The user can also pre-create part master data into the MMS which can then be imported to the real production MMS after testing.
4) Long-term simulation runs (in the future): Long-term simulation runs will allow the user to get a detailed view of the future production rate and projected machine utilization of the cell. This allows the user to test their future production capacity before committing to a new order.

2.15 Use-case demonstration 15: IIoT Robustness Simulation

This demonstration is owned by Fraunhofer IWU. The goals of this use case demonstrator are manifold. Firstly, robustness of wireless networks in production/IIoT environments should be increased. In this use case, a production environment is considered as an IIoT environment because modern production contains various digital devices, sensors and actuators. Thus, we use these terms interchangeably. Secondly, wireless networks should be put into service faster since currently, their deployment is very time consuming.

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Thirdly, this use case should enable SMEs to build up robust, reliable, cost- and time-efficient IIoT infrastructure.

2.15.1 Description

Wireless networks (WN) are essential in production/IIoT environments. Mobile robots, edge devices, or Automated Guided Vehicles need to communicate. Such networks are prone to physical changes of the environment and cyber-attacks. This use case simulates the WN behavior in IIoT infrastructure and validates it against real environments. The developed simulation results in an optimal positioning of the network devices and evaluates fallback strategies for cyber-attacks.

For achieving the aforementioned goal, the simulation platform *d3vs1m* (https://github.com/adriansinger87/d3vs1m) has been developed. It can simulate antennas' behaviors (see Figure 24) and the radio behavior inside buildings (Figure 25) in order to come up with a 3D radio map (see Figure 26) for being able to make assumptions about the coverage of the wireless network.

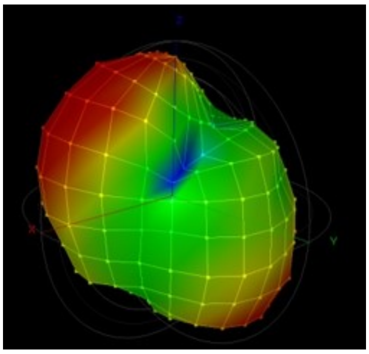

Figure 24: 3D simulation of 868MHz PCB antenna

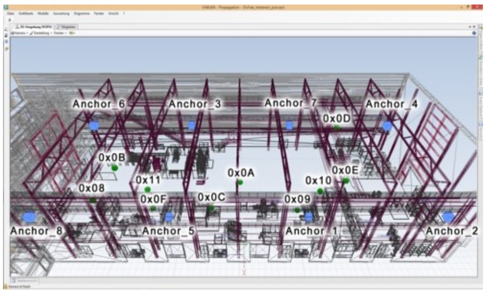

Figure 25: Radio simulation with 18 nodes inside E³ Research Factory (https://www.e3-fabrik.de/en.html)

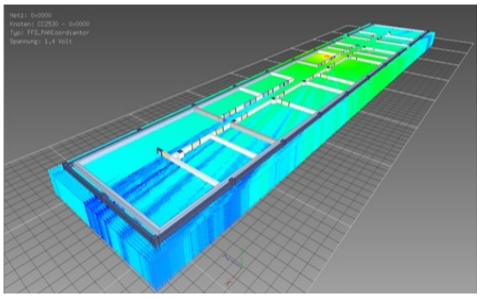

Figure 26: 3D radio map in office environment

The simulation of cyber-attacks and their fallback strategies is currently under development.

The used hardware components are Wireless (Sensor) Network with multiple IIoT devices. The main software component used is Software *d3vs1m* (https://github.com/adriansinger87/d3vs1m). This simulation platform is available under the GNU General Public License v3.0 (https://www.gnu.org/licenses/gpl-3.0.en.html). Thus it can be downloaded, compiled and used individually without any warranty. In addition, it is planned to provide it as a web-based service which can just be used easily. The relevant standards and specifications addressed here are IEEE 802.15.4 (LR-WPAN), IEEE 802.11 (WLAN), CUDA, OpenCL, web standards (WebGL, HTML5, CSS3).

2.15.2 Value-added from IIoT robustness simulation

The value added comes from the reduction of setup time of WSNs in IIoT infrastructures, simulation of robustness against wireless communication failures (unwanted system behavior or criminal attacks), optimization of positioning the network devices (node distribution).

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2.16 Use-case demonstration 16: Flexible automation for agile production

This demonstration is owned by Fraunhofer IWU and LP-Montagetechnik. The main goal is to demonstrate flexible handling solutions for assembly process.

2.16.1 Description

Highly flexible solutions for handling and clamping parts during the assembly process are needed to realize small lot sizes with a high variety. Flexible grippers and jigs are a possible solution. Requirements of different product types must be considered while planning, designing and constructing such systems. The main idea is to develop methods for planning and designing such tools and jigs. The use case is demonstrated for the LED-lamp production, Figure 27.

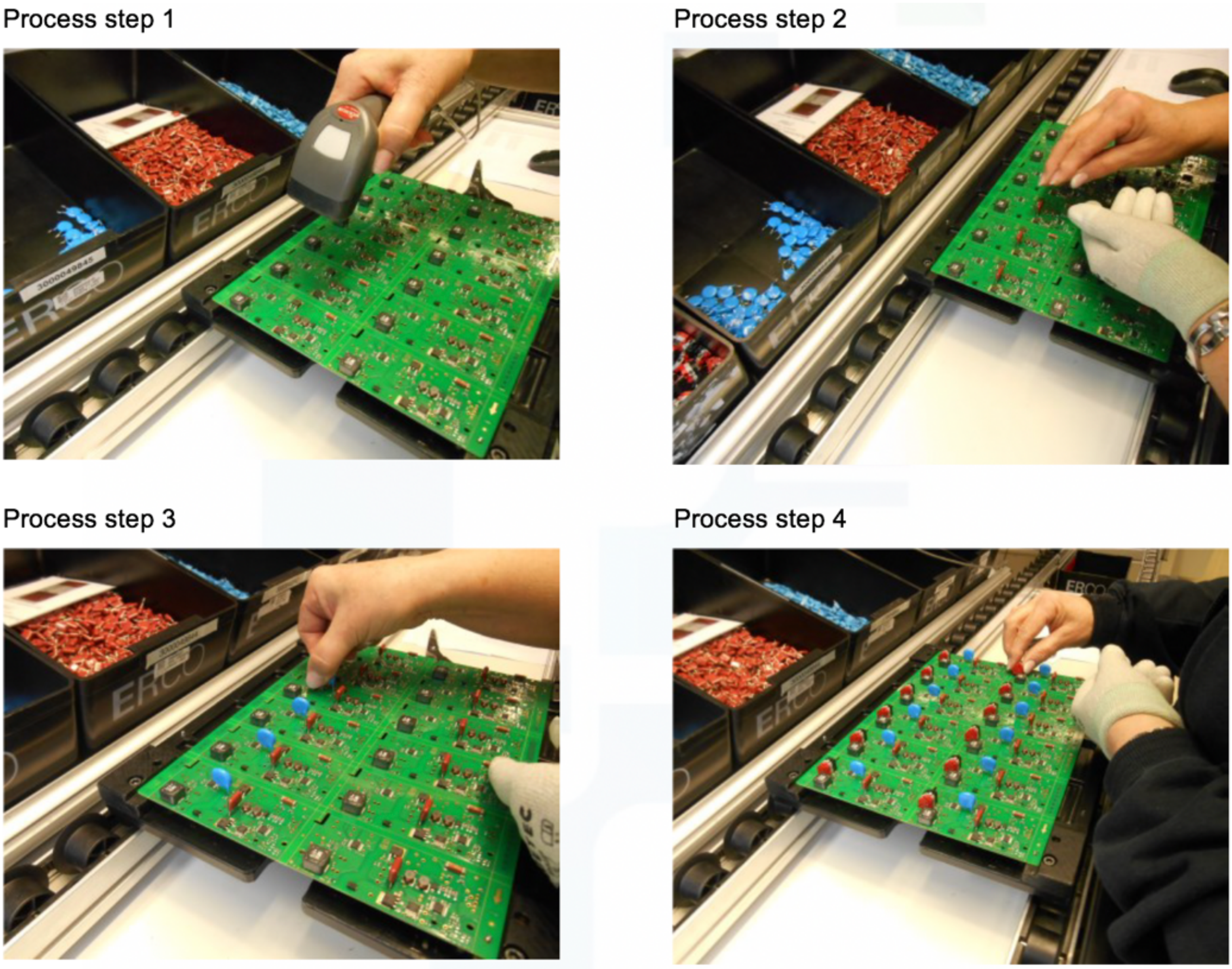

Figure 27 Test case for the demonstrator

The used hardware components are Industrial robot arm, vision system (hardware), gripper. The main software components used are Vision system (software). The relevant standards and specifications addressed here are C# (ISO/IEC 23270:2006), computer graphics and image processing – The Virtual Reality Modeling Language (ISO/IEC 14772-1:1997; ISO/IEC 14772-2:2004).

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2.16.2 Value-added from vision based flexible assembly

A method to identify and rate automation potential of different workplaces, an approach for creating a highly flexible production system for products in small lot sizes and high variety will be demonstrated, a summary of design rules for manual work place design will be compiled.

2.17 Use-case demonstration 17: Artificial intelligence based stereo vision system for object detection, recognition, classification and pick-up by a robotic arm

This demonstration is owned by Institute of Electronics and Computer Science (EDI). The goal is to enable automation of industrial processes involving large number of different kind of objects with unpredictable positions. The potential users are SMEs that are willing to optimize the production process by using AI based robotic arms.

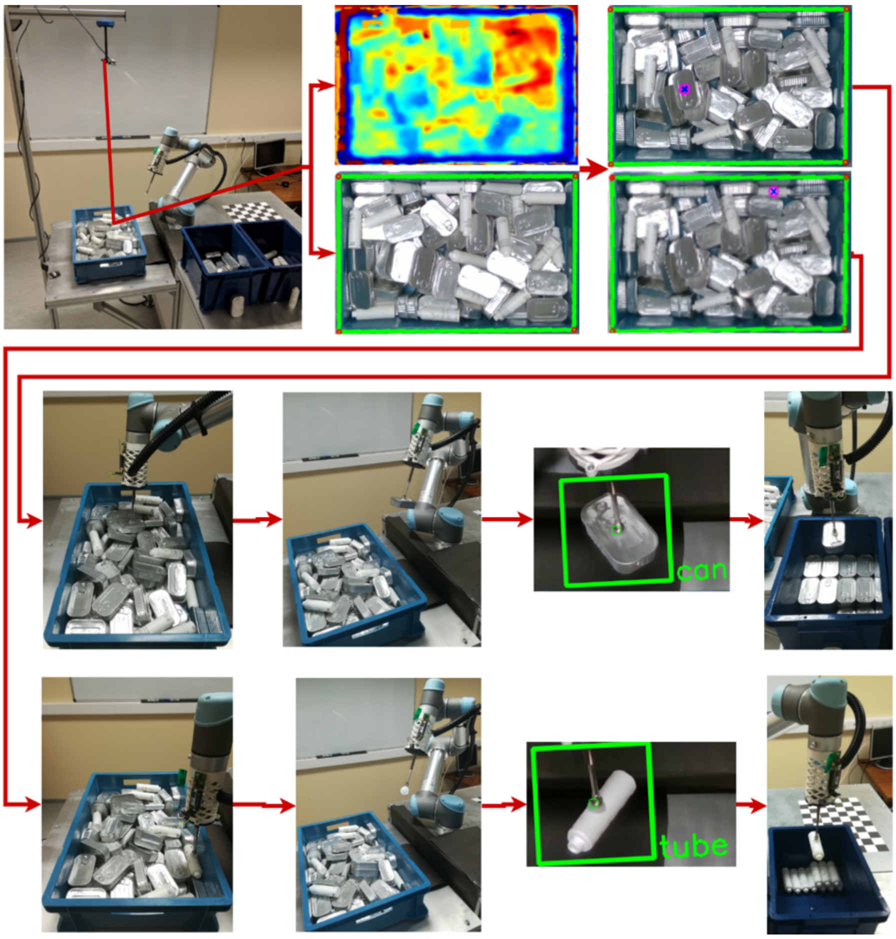

Figure 28 Feature recognition and classification process

2.17.1 Description

A lot of industrial processes involve operation with large number of different objects with arbitrary location. It is hard to automate these kinds of processes because sometimes it is impossible to predetermine the positions for these objects. To overcome this issue, we integrate 3D and 2D computer vision solutions with

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AI and robotic systems for object detection, localization and classification, Figure 28. The main hardware of demonstrator is RealSense stereo camera and collaborative industrial robot UR5. The architecture of the demonstrator is based on open source software ROS, which enables comparatively easy integration with different kind of sensors and robots.

2.17.2 Value-added from AI-based enhanced object recognition in pick'n'place applications

Possible benefits of the demonstrator are algorithms and methods, which are based on AI. These algorithms and methods will allow to generate labelled data for various objects a lot faster with reduced amount of manual work allowing faster adaption of system which is capable of randomly dropped object detection, recognition, classification and pick-up by a robotic arm for different scenarios.

2.18 Use-case demonstration 18: Rapid development, testing and validation of large scale wireless sensor networks for production environment

This demonstration is owned by Institute of Electronics and Computer Science (EDI). The goal is to decrease time to market for large scale WSN implementation in production environment. The potential users are SMEs willing to increase the performance of their production/manufacturing equipment by using wireless sensor networks (WSN).

2.18.1 Description

This demonstration is based on EDI TestBed, Figure 29, that allows to smoothly pass from one development stage to another (e.g. from lab to industrial environment). EDI TestBed is located in EDI premises in Riga, it consists of 2 parts: 1. EDI Indoor WSN TestBed (100 nodes) and 2. EDI mobile WSN TestBed (50 nodes) EDI Indoor WSN TestBed. EDI indoor WSN TestBed is a 100+ node heterogeneous WSN testbed. EDI mobile WSN TestBed has the same capabilities as EDI Indoor WSN TestBed only it is not "tied" to one location and can be moved to actual factory, to perform the tests in real production environment.

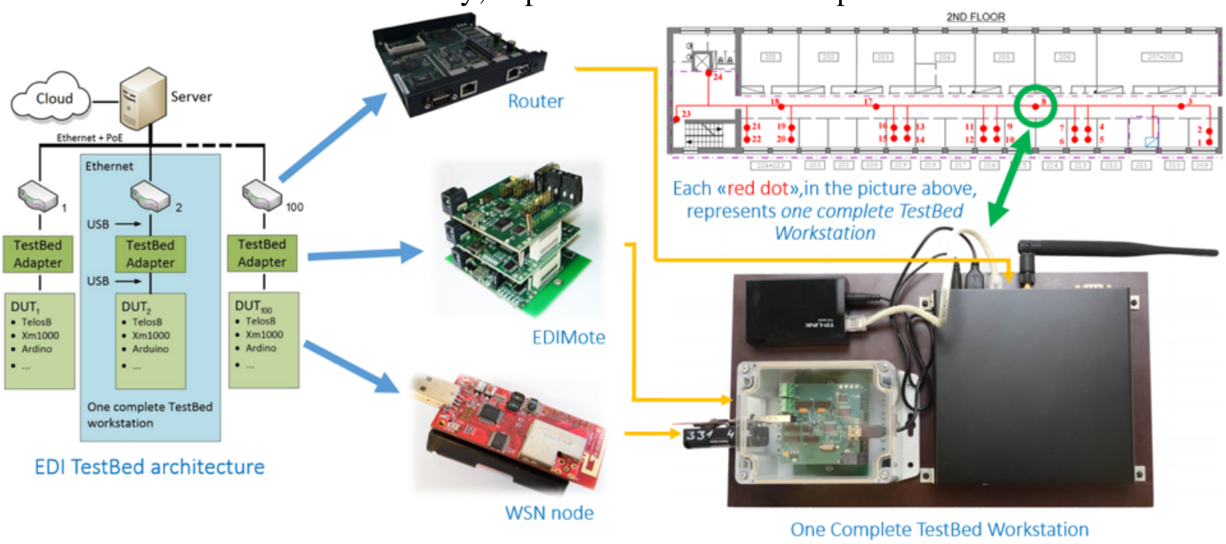

Figure 29 WSN TestBed

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2.18.2 Value-added from the deployment of large scale WSN

Possible benefits are time reduction to market for large scale wireless sensor networks envisioned for use in production environment. It is expected to reduce development time by 20-30% and testing/validation time by 60-70%.

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3 Modules

The demonstrators presented in Chapter 2 are integrated systems that showcase advanced robot technologies that can be employed in agile manufacturing systems. In this chapter we present stand-alone modules, which are typically components of the above-described demonstrators. They can be made available for industrial applications as need arise and can be transferred without a large integration effort.

Table 1 List of Published modules developed for the use case demonstrations so far

Use Case	Owner	Module name	Description
Use case demonstration 1: Collaborative assembly with vision-based safety system	TAU	Projection-based interaction interface for HRC	The module intents to increase the human operator awareness, safety and capabilities during a human-robot collaboration in a shared workspace. Software module creates and visualize a dynamic safety hull around the robot using a standard projector installed to the ceiling. In addition, user-defined interface components can be created and projected to the workspace.
Use case demonstrations 1) Collaborative assembly with vision-based safety system, and 2) Collaborative disassembly with augmented reality interaction	TAU	Depth-sensor safety model for HRC	The module provides a depth-based safety model for human-robot collaboration. Generates three different spatial zones in the shared workspace which are then online modelled, updated and monitored.
Use case demonstration 2: Collaborative disassembly with augmented reality interaction	TAU	Wearable AR-based interaction interface for HRC	Software module creates and visualize a dynamic safety hull around the robot as 3D holograms which are visualized using a wearable display, in this case Microsoft HoloLens. Similarly, as in module 1, additional user-defined interface components can be created and projected to the workspace as 3D holograms. https://github.com/Herrandy/HRC-TUNI.git
Use case demonstration 3: Collaborative robotics in large scale assembly, material handling and processing	Centria	Safe human detection in a collaborative work cell	Solution for creating safe collaborative working cell for robots and human workers performing tasks such as assembly together. Target is to provide flexible and adaptive way to create dynamic safety areas based on information from a laser scanner or a safety camera system. The solution is based on commercial tools.
Use case demonstration 3: Collaborative robotics in large scale assembly, material handling and processing	Centria	Dynamic online trajectories generation for industrial robot with 3D camera	A solution for providing depth based real-time information of workspace for generating dynamic trajectories for robot. This module will provide a flexible and adaptive way to generate robot trajectories for safe human-robot collaboration based on information from 3D-camera(s).
Use case demonstration 3: Collaborative robotics in large scale assembly, material handling and processing	Centria	Dynamic robot trajectory generation based on information from 3D-camera	This module has two functionalities: the first one is to provide flexible and adaptive way to create robot trajectories dynamically based on point cloud data created automatically with 3D-camera. Camera can be mobile in example attached to industrial robot as a tool or stationary installation. Secondary functionality is to provide point cloud data of scanned object and save it as file. In this case only 3D-camera and Cloudcompare is needed.
Use case demonstration 4: Integrating digital context (e.g. BIM) to the digital twin with AR/VR of the robotized production	Centria	Robot trajectory generation based on digital design content	This module has two functionalities first one is utilizing digital design information for robot simulation, online or offline programming online and offline. The target of this functionality is to speed up robot simulation and

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			programming by using data from digital design data, such as BIM. Secondary functionality is to utilize design data to create AR and VR models. The target is to speed up the creation of AR and VR models or virtual twin models by using data from digital design.
Use case demonstration 5: Wire arc additive manufacturing with industrial robots	UiT	Real-time simulation for industrial robot	The module contains simulated robot/machine which constantly imitate the robot/machine in physical world in real-time. In physical world, the robot joint data and machine state will be updated to a server through Ethernet. In simulation, robot and machine will imitate the physical world by acquiring data from the server. To do analyses on the robot/machine afterward, there will be saved historical data in a CSV file. The data collected can be used for optimization of the program and used to look for errors in the program.
Use case demonstration 5: Wire arc additive manufacturing with industrial robots	UiT	Remote control for industrial robot	Remote controlling of industrial robot. This module offers a robot controlling method through Ethernet and update robot joint value to a robot information server. The present GUI as input method is running on specific PC, running GUI on multiple devices will be developed in the future.
Use case demonstration 9: Dynamic task planning & work re-organization	LMS	Dynamic task planning & work re-organization	This module provides a decision-making algorithm enabling the automatic line reconfiguration considering concurrently the task planning issues. This will allow the evaluation of a huge number of alternative solutions in a short time frame, even in cases where reconfiguration of the workplace is needed. A suitable workcell layout and task planning regarding the available human and robot resources will be generated automatically.
Use case demonstration 10: HRI framework for operator support application in human robot collaborative operations	LMS	AR-based operator support in HRC	The integration and communication architecture monitor the communication of resources and sends-receives messages, while supporting the human operators through the AR Application, in order to be aware of the execution status of every operation. It also provides a dedicated, web-based user interface that allows a user with the appropriate rights to oversee the production status through a browser.
Use case demonstration 10: HRI framework for operator support application in human robot collaborative operations	LMS	Safety logic for seamless HRC	This module refers to the safety architecture that has been implemented and includes all the safety certified technologies used to ensure human safety inside the collaborative cell. The layout of the cell has been regulated in accordance with the implemented safety systems.
Use case demonstration 11: Robotized serving of automated warehouse	Fladers MAKE	UWB based indoor localization	The Localization module will generate a two-dimensional location and heading of the mobile robot in the world model using Ultra-Wideband (UWB) technology based on the IEEE 802.15.4a standard. It will localize independent of the localization capabilities indigenous to the mobile platform. Therefore, it can also be added to any mobile platform without localization abilities or replace existing expensive other localization technologies, e.g. laser scanners.
Use case demonstration 7: Robot workcell reconfiguration	JSI	ROS peripheral interface	The module provides a ROS interface to pre-existing peripheral elements that lack ROS compatibility. It acts as a proxy between the standard periphery connections and the ROS system. It allows users to quickly integrate existing cell periphery into the ROS-based software system. It can be customized to meet the needs of different production system peripheral equipment in terms of shape, size and connectivity.

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Use case demonstration 8: Efficient programming of robot tasks by human demonstration	JSI	Hardware & software interface for kinesthetic guidance	Kinesthetic guidance proves to be a considerably more intuitive approach to guide the robot through the desired motions in a programming by demonstration systems. This module provides a user-friendly hardware and software interface to gather data for robot programming via kinesthetic guidance.
	JSI	SMACHA Scripting Engine for Task Execution Control	SMACH is an exceptionally useful and comprehensive task-level architecture for state machine construction in ROS-based robot control systems. However, while it provides much in terms of power and flexibility, its overall task-level simplicity can often be obfuscated at the script-level by boilerplate code, intricate structure and lack of code reuse between state machine prototypes. SMACHA aims at distilling the task-level simplicity of SMACH into compact YAML scripts in the foreground, while retaining all of its power and flexibility in Jinja2-based templates and a custom code generation engine in the background.
Use case demonstration 16: Flexible automation for agile production	IWU, LP	MTM Universal Analysis System (UAS)	System of predetermined time units to calculate the manual effort of the human in production environments. Results of the analysis are useful for planning future operations, calculations, change management, optimization and visualization of current process state (primary and secondary analysis)
Use case demonstration 15: IIoT Robustness Simulation	IWU	IIoT Network Device Positioning	This module provides our simulation environment d3vs1m (https://github.com/adriansinger87/d3vs1m) in order to compute the optimal distribution of the network devices located inside a physical building. It takes a 3D model of the building and other additional properties of the wireless radio devices as input and simulates the behavior. Depending on the simulation result an optimal distribution of the network devices is calculated.
Use case demonstration 15: IIoT Robustness Simulation	IWU	IIoT Network Fallback Simulation	This module provides our simulation environment d3vs1m (https://github.com/adriansinger87/d3vs1m) in order to simulate the network behavior, specified with the IIoT Network Device Positioning, and a selected cyber-attack scenario. It takes a 3D model of the building and other additional properties of the wireless radio devices as input and simulates the behavior. Depending on the simulation result the user gets the adapted network behavior.
Use-case demonstration 11: Robotized serving of automated warehouse	BME	Queued Message Handler (QMH) software architecture	The main functionality of the module is to organize the whole software in separate tasks (modules) and execute them in parallel at different execution rates.
Use case demonstration 13: Deployment of mobile robots in collaborative work cell for assembly of product variants	BME	Robotino® communication (Commercial product by Festo)	The main functionality of the module is to communicate with the Robotino® . The Robotino® is a mobile robot platform for research and education developed by Robotics Equipment Corporation GmbH (http://www.servicerobotik.eu/) and distributed by Festo Didactic.
Use case demonstration 13: Deployment of mobile robots in collaborative work cell for assembly of product variants	BME	Environment detection	This module consists of three sub-modules, each performing different sensory tasks: 1) Optical character recognition (OCR): the main functionality of this sub-module is to recognize human readable characters from images; 2) Object detection by chromatic discrimination: the main functionality of this sub-module is to detect

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			objects on an image based on their color; and 3) Optical line following: the main functionality of this sub-module is to implement movement algorithms along optically detectable tracks on the ground.
Use case demonstration 13: Deployment of mobile robots in collaborative work cell for assembly of product variants	BME	Mobile robot motion control	This module consists of two sub-modules, each performing different motion control tasks. 1) Open-loop motion control: the main functionality of this sub-module is to perform different pre-programed or time-controlled movement patterns. 2) Machine vision-based closed-loop motion control: the main functionality of this sub-module is to implement closed-loop motion control algorithms based on machine vison calculations executed on images.
Use case demonstration 17: Artificial intelligence based stereo vision system for object detection, recognition, classification and pick-up by a robotic arm	EDI	Object detection	The object detection module is used to perceive the changing environment and modify systems actions accordingly. The module receives color frames and depth information from a camera sensor and returns information about objects to the robot control. The camera sensor could be placed above the pile of objects as well as at the end-effector of the robot manipulator. The object detection module is mainly responsible for object detection from the bin that can be picked by an industrial robot.
Use case demonstration 17: Artificial intelligence based stereo vision system for object detection, recognition, classification and pick-up by a robotic arm	EDI	Object classification	A deep convolutional neural network (CNN) is used to classify and sort objects. When industrial robot picks the object, it is then classified using convolutional neural network. This module allows for sorting different types of objects, where two different kinds of objects are being sorted. In order to train the classifier to recognize new classes of objects, new training datasets must be provided.
Use case demonstration 17: Artificial intelligence based stereo vision system for object detection, recognition, classification and pick-up by a robotic arm	EDI	Robot control for bin picking	Robot control for bin picking works as an integrator of object detection and classification modules or any other system which provides pickable object data. This module is mainly responsible for movement and trajectory creation depending on object position in the container, object class or other information from sensors. In the selected demonstration example for picking and placing of arbitrary arranged different objects, the robot movement is implemented in following way – linear path generation for picking up an object respectively to its position and orientation, while avoiding collisions with obstacles in the environment, linear path generation to move object in classification position to classify what kind of the object has been picked and other features of the object, after that the object is moved to appropriate position(box) depending on classification result.
Use case demonstration 18: Rapid development, testing and validation of large scale wireless sensor networks for production environment	EDI	WSN/IoT TestBed	Access EDI Wireless Sensor Network/Internet of Things (WSN/IoT) TestBed functionality – remotely reprogram multiple sensor nodes, control serial communication with sensor nodes, start and stop experiments and retrieve historical experiment data. This 100+ node TestBed is in EDI, Riga, Latvia and is distributed across 7 floor building but can be access from anywhere form the world. TestBed includes some outdoor nodes and some mobile nodes capable of providing full testbed functionality anywhere with internet connection.

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4 Conclusions

In the first year of the project we have started to work on the development of 18 internal demonstrators. 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/. The demonstrations can be distributed over the TRINITY thematic topics, Figure 30.

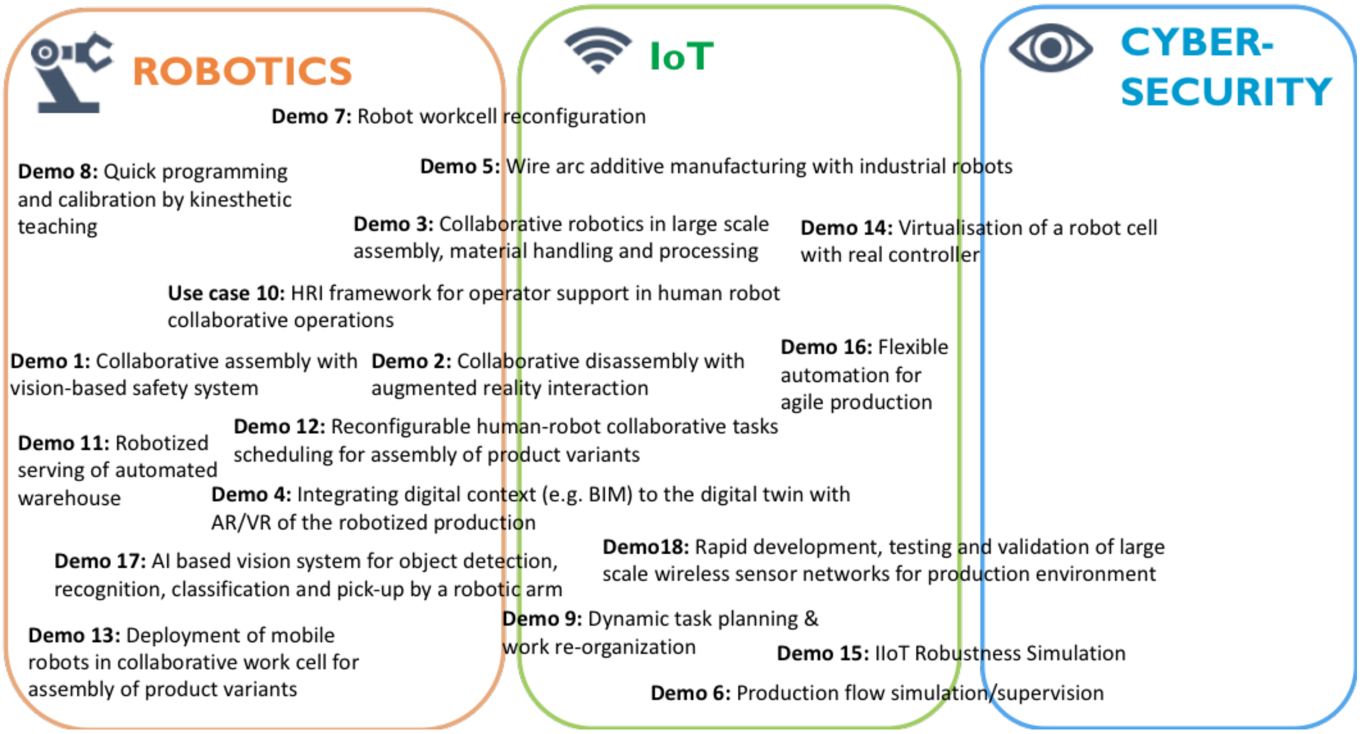

Figure 30 Use case demonstrations distributed over the thematic areas

Besides the demonstrators, we also present 27 modules in this deliverable. The modules are typically self-contained pieces of hardware and software, which can be offered to industrial partners for integration in their production processes. Some of the modules have already been made available to potential external users at https://trinityrobotics.eu/modules/. More will be made available as the project progresses.

Both the demonstrators and the modules showcase advance robot and IoT technologies, which can contribute to the development of agile manufacturing processes. The current versions serve as a guideline for the first TRINITY open call, which is opened until February 28th, 2020 (https://trinityrobotics.eu/calls/trinity-dih-agile-production-open-call-for-up-to-e300000/).

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