

COLLABORATE

# Technology Handbook

Enabling genuine  
human-robot collaboration  
for performing assembly tasks  
in a co-production cell



# The Handbook

The purpose of this handbook is to provide an overview of the CoLLaboratE system and of the technologies developed within the project. This handbook is targeted to manufacturing industries in need of flexible and affordable automation systems to boost their global competitiveness. The goal of the project is to allow SMEs and large manufacturing companies in Europe to easily program assembly tasks and flexibly adapt to changes in the production pipeline.

## The catalogue:



Provides an overview of the CoLLaboratE system.



Gives a detailed description of the innovative technologies offered by the partners that will enable companies in Europe to identify technologies that would be valuable to implement in their organizations.



Describes the use cases showcased within the project.

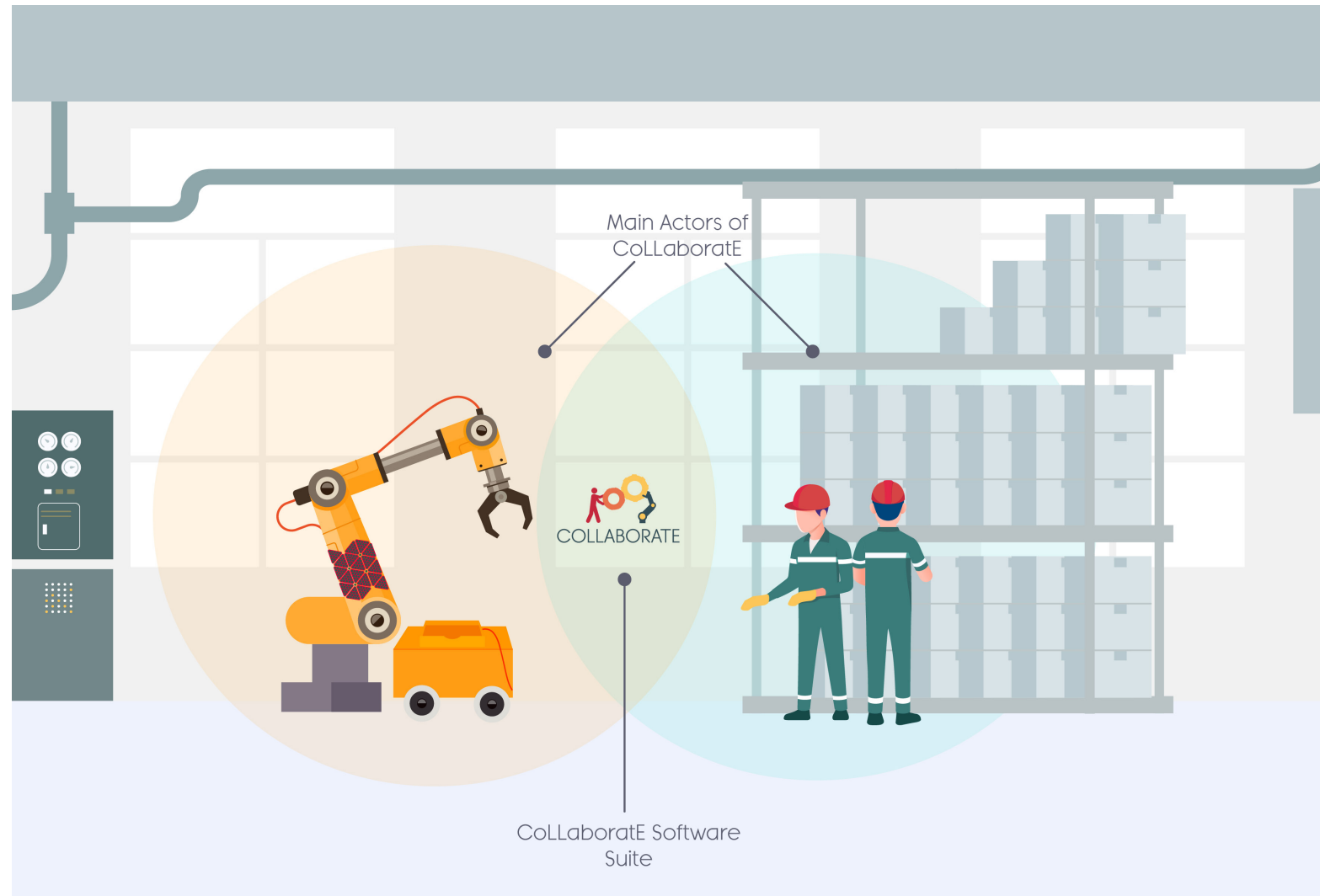
## Reading guidance:

This handbook first presents an overview of the CoLLaboratE system. It then consists of the technologies developed in CoLLaboratE. In total, 15 technologies are developed within the project. Each technology is described and illustrated with a picture. Furthermore, the technology requirements, technology application, technology readiness level, its provider and target market are listed as well. In the end of the handbook there are presented 4 use cases with different types of assembly tasks to show the variety of applications of the CoLLaborate system.



# The CoLLaborate System

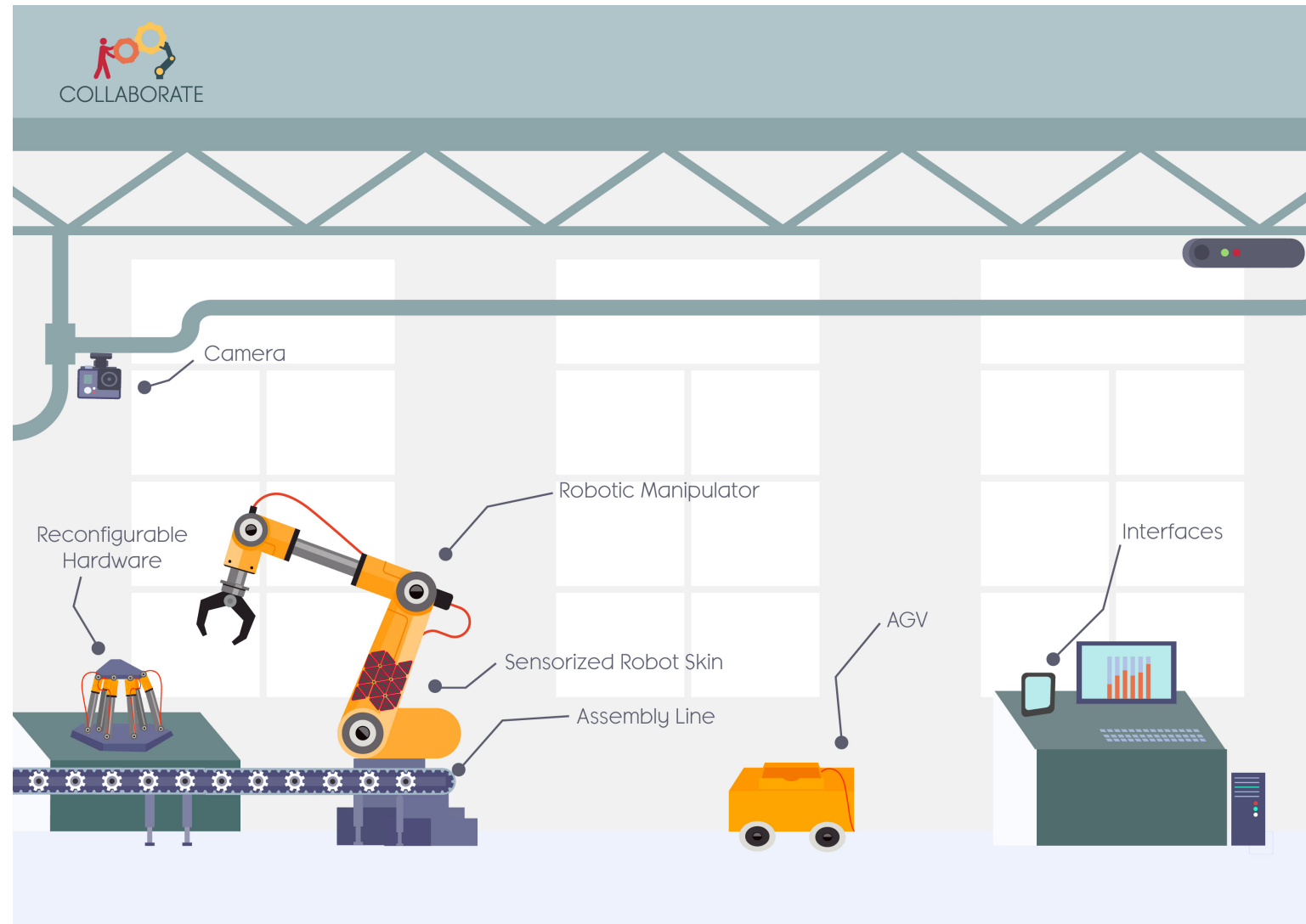
The CoLLaborate system is a software suite that equips robotic agents with basic collaboration skills, enabling them to easily adapt to specific tasks and work together with humans.



# The CoLLaborate System

The system is hardware-agnostic and can therefore be used with most commercially available robotics manipulators and AGVs (Automated Guided Vehicles).

With the right type of additional hardware such as sensors, processing units and specialized grippers, the CoLLaborate system can be tuned to fit a wide range of use case requirements with only slight software modifications.

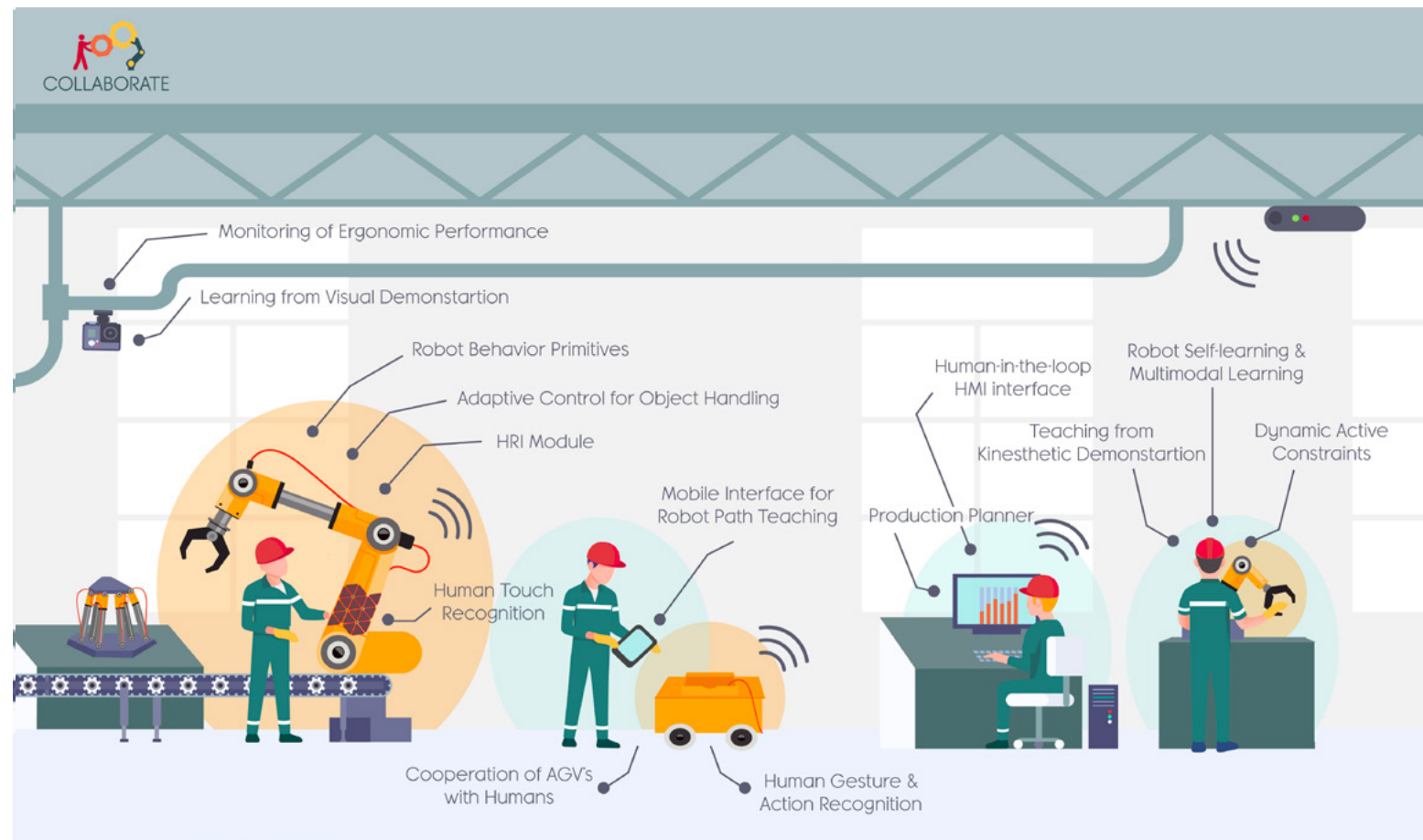


# The CoLLaborate System

The CoLLaborate software suite is a build-up of different modules that interact with each other to equip the robots with collaborative skills. Some modules can operate independently, others are dependent on input from other modules. In the first step, the robot is demonstrating the assembly task.

Due to the CoLLaborate Modules, no expert in robotics is needed for this. In a second step, the robot is executing the assembly task. The modules get input from sensors and allow safe collaborative work with humans. They also autonomously learn from prior knowledge and data. Especially SMEs require flexible, safe and adaptable assembly processes.

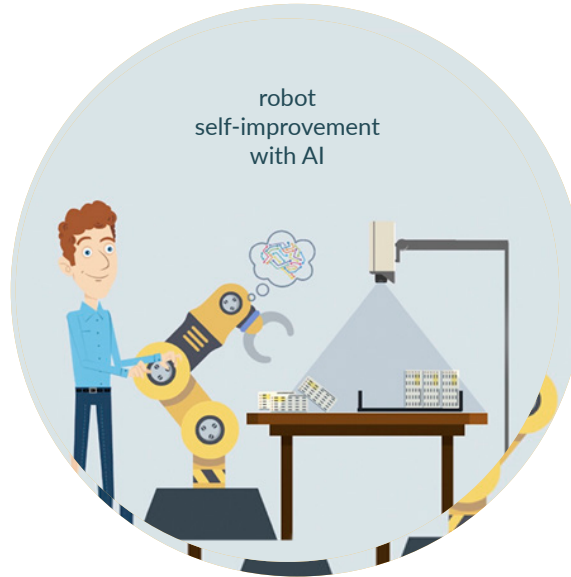
Thanks to the CoLLaborate Modules, the robot can adapt to different assembly tasks, and perform its knowledge to the new situation. The robot is also proactive and adapts to the intentions of the human.



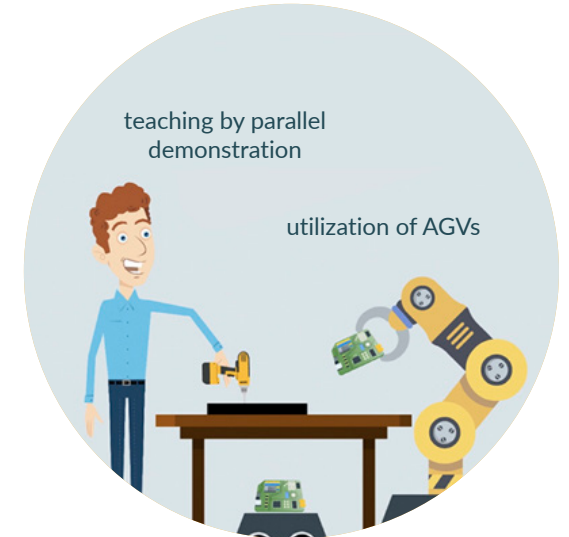
Read more about all CoLLaborate Modules on the next pages

# The CoLLaborate System

Use-case 1:  
Car starter assembly



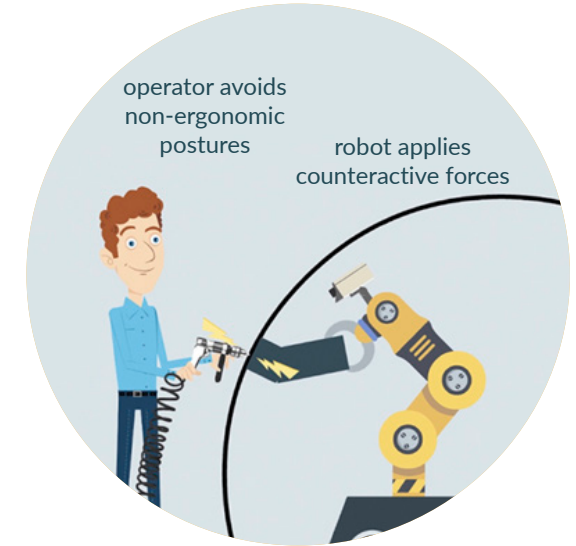
Use-case 3:  
LCD TV assembly



Use-case 2:  
Windshield assembly  
& inspection



Use-case 4:  
Aerospace structure  
riveting

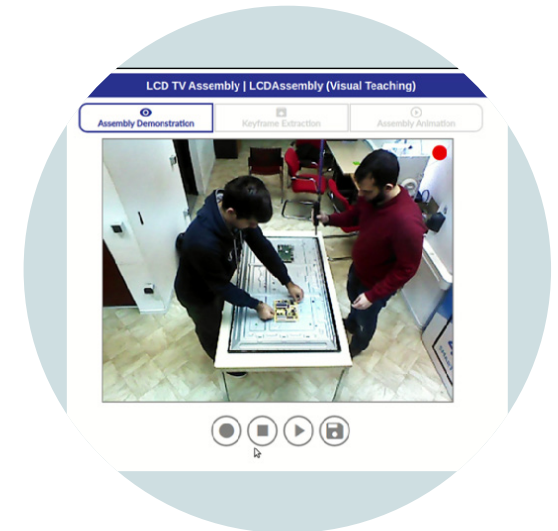




# Learning from visual demonstration

The developed technology allows human workers to teach the robotic system a new collaborative assembly task simply by visual demonstration of the assembly. The workers perform the assembly in front of an RGBD sensor that acquires registered image and depth data, which are employed by the system for tracking both the assembly parts and the instructors' bodies.

The tracking results are utilized by the system to perform semantic analysis of the demonstrated sequence and extract important steps of the assembly procedure called key-frames. The kinematic and semantic information of each key-frame is then utilized by the system to parametrize a behavioral tree and automatically generate the robot program for performing the collaborative assembly by substituting one of the workers.



## Technical requirements

Methods to effectively encode and analyze the demonstration (software) are required for the solution. An RGBD sensor is required for acquiring the visual data of the demonstration. An external computer is required to record and process the data by executing the developed software. A PC Tablet is required for interacting with the system throughout the demonstration via the web-based GUI.

## Technology readiness level



## Technology application

Robot programming (fast and intuitive without requiring expertise in robotics). No special training is required for the instructors, since the entire procedure is guided through an intuitive web-based graphical user interface designed and developed specifically for Human Robot Interaction applications.

## Target market

Industries / SMEs  
with assembly  
production lines

## Technology provider

Centre for Research and Technology Hellas  
(CERTH) / Information Technologies Institute (ITI)

[www.certh.gr](http://www.certh.gr)  
[www.iti.gr](http://www.iti.gr)





## Learning from kinesthetic demonstration

The technology allows human workers to demonstrate the assembly task to the robot with kinesthetic guidance. The human can grab the robotic manipulator and easily demonstrate the task, while the robot records and encodes the trajectory. This is a fast and intuitive method that reduces programming time and also allows the human to make modifications to the task. This technology is not application oriented but a basic enabling technology for faster robot programming that can be used to any collaborative robot.

The technology is intuitive enough so that the user can teach to a robot various tasks without having high expertise. For example, an assembly task can be programmed in a few minutes without requiring external sensors or having to interact with the robot's teaching pendant. No training is required for the user. At this point, it can be potentially used with any collaborative robot manipulator.



### Technical requirements

The robot manipulator must be collaborative, allowing hand guidance mode.

### Technology application

Robot programming (fast and intuitive without requiring expertise).

### Target market

Industries  
SMEs

### Technology readiness level



### Technology provider

Aristotle University of Thessaloniki /  
Automation and Robotics Lab

[arl.ee.auth.gr](http://arl.ee.auth.gr)





## A Mobile Interface for Robot Path Teaching

Robot programming methods for industrial robots are time-consuming and often require operators to know about robotics and programming. This technology proposed a novel augmented reality interface to create new intuitive means of controlling and programming robots in real-time and without having to code. The software can be installed on smartphones and tablets, providing operators with the ability to monitor and program robot tasks onsite. It can also be used to create a virtual representation of the workspace which can be saved and reused to program new tasks or adapt old ones without having to be co-located with the real robot. The location of the phone is estimated so that we can render 3D graphics on top of the camera's image, which is continuously displayed on the screen. The smartphone then appears to the user as a transparent window frame that can be moved freely, on which virtual 3D objects can be superimposed as if they were part of the real world. The technology can be used to teach and modify trajectories through the smartphone interface, using via-points without the need of programming the whole trajectory. It can be also used to visualize a demonstrated movement with the virtual robot as a validation step before running the program on the real robot.



### Technical requirements

The model of the robot in URDF format and basic knowledge of the ROS environment is required for a new robot. It also requires a smartphone with Google ARCore toolkit and IDIAP's developed app installed in it.

### Technology application

It allows users to program new tasks on the robot, to visualize the motions that the robot has learned, and to monitor robot motions before execution on the real robot.

### Target market

Industries  
SMEs

### Technology readiness level



### Technology provider

Idiap Research Institute

[www.idiap.ch](http://www.idiap.ch)





## Adaptive control for object handling

This technology can be used for easy collaborative handling of large and heavy objects to targets that are unknown to the robot. The robot becomes aware of the human's intentions by predicting the target and thus offers better and more intuitive assistance by becoming proactive during the collaborative handling. No training is required for the user.



### Technical requirements

The robot manipulator must be collaborative to allow hand guidance for an initial demonstration and encoding by DMP of the desired handling pattern. The robot or its gripper should be sensorized to allow measurement of forces and torques applied by the user. The robot should be able to compensate the object's weight.

### Technology application

Collaborative handling between the human and the robot.

### Target market

Industries  
SMEs

### Technology readiness level



### Technology provider

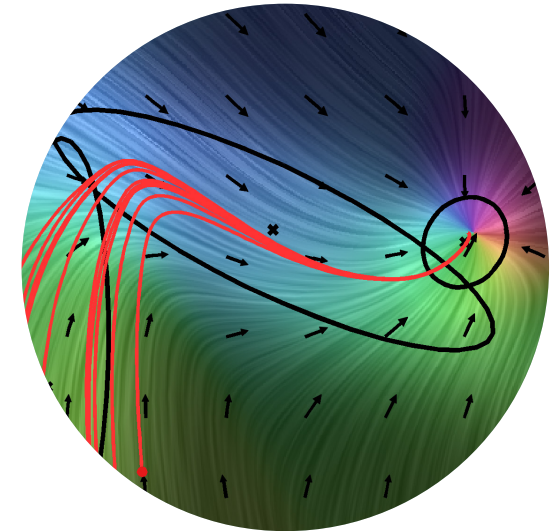
Aristotle University of Thessaloniki /  
Automation and Robotics Lab

[arl.ee.auth.gr](http://arl.ee.auth.gr)



## Robot behavior primitives

The objective of this technology is the development of robust and adaptive behaviors that are typically encountered in a large variety of human-robot collaboration scenarios that the CoLLaboratE project focuses on. It addresses challenges in programming and re-programming robots by non-expert users to easily teach required skills to a robot. Learning these skills requires generalizable and flexible movement representations which are called movement primitives. These are considered as “building blocks” or “bricks” that can be combined in parallel and in series to achieve a collaborative assembly. This technology extends movement primitives using diverse methods from machine learning and nonlinear control to more complex and smart behaviors called behavior primitives. Such behaviors include various representations, including the combination of time-dependent and time-independent movements, cyclic patterns, search patterns, manipulability behaviors, impedance behaviors, and reactive behaviors.



### Technical requirements

The technology requires robot sensors for position/velocity/torque measurements and/or external sensors for force measurements.

### Technology application

It can be used to improve adaptation and safety in industrial robotic tasks. It can combine different movement models for better generalization capabilities.

### Target market

Industries  
SMEs

### Technology readiness level



### Technology provider

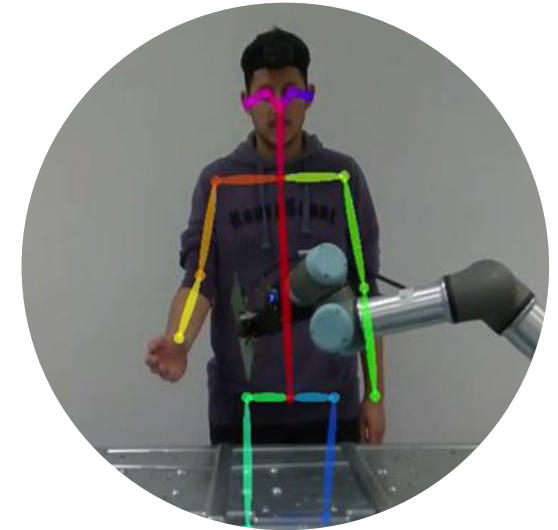
Idiap Research Institute

[www.idiap.ch](http://www.idiap.ch)



## Human gesture & action recognition

Robot collaboration requires a smooth, natural and efficient coordination between robot and human industrial operators. This is accomplished with the recognition of a series of human gestures and/or actions performed in production lines (e.g. to screw, to assembly, etc.) by the robot, as captured by an RGB-D camera. The developed algorithm provides the recognized gesture's ID, which is directly being sent to the robot or the AGV to be interpreted accordingly.



### Technical requirements

Professional action recognition is achieved by analyzing, capturing and recognizing the movements of industrial operators, with the use of RGB-D cameras and machine learning techniques.

### Technology application

Industrial environments where specific gestures are part of the work routine.

### Target market

Industries

### Technology readiness level



### Technology provider

ARMINES - MINES ParisTech

[www.armines.net](http://www.armines.net)  
[www.mines-paristech.fr](http://www.mines-paristech.fr)



## Cooperation of AGVs with humans

This technology will allow the Autonomous Guided Vehicle (AGV) to understand the human's intentions and basic commands through a series of gestures. Gestures are being received using a 3D camera system that is communicating with the controller of the AGV. These gestures are translated to digital signals and commands.

This technology allows inexperienced users to communicate in an easy way with the AGVs and command it. In addition, it boosts the adoption of the AGVs solutions in industries.



### Technical requirements

The main requirement is an Autonomous Guided Vehicle. Additional hardware with a 3D camera mounted on top. Gestures and command must be pre-configured, also the system needs a minimum distance to humans.

### Technology application

Industrial environments where AGVs are present. This technology could replace current communication systems between AGVs and humans.

### Target market

Automotive sector and manufacturing industries

### Technology readiness level



### Technology provider

ARMINES - MINES ParisTech  
& ASTI Mobile Robotics

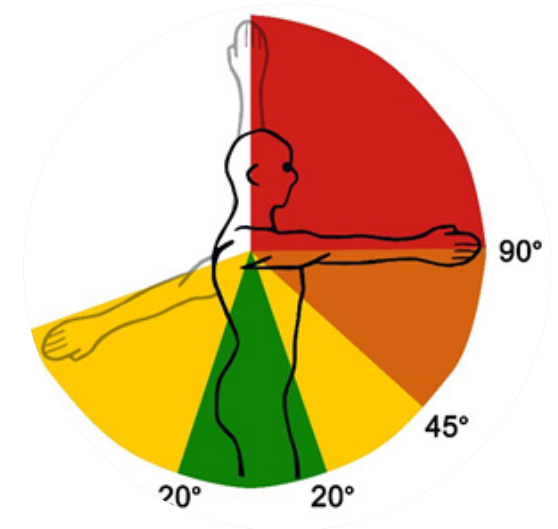
[www.armines.net](http://www.armines.net)  
[www.mines-paristech.fr](http://www.mines-paristech.fr)  
[www.asti.es](http://www.asti.es)



## Monitoring of ergonomic performance

Industry operators perform many repeated postures in their everyday working routine. In time, this constant repetition might cause discomfort and later on trauma in the musculoskeletal system.

To address this issue, an ergonomic performance assessment is performed. It provides an in-depth insight into the impact of the industrial task as it progresses through time. By monitoring the strain of the industrial operator, it is possible to avoid chronic injuries that permeate the workforce of the production line. This translates to a better quality of life for each employee and significant cost reduction for the company.



### Technical requirements

This is implemented with the use of Inertial Measurement Units (IMUs) and a deep learning application that allows the extraction of features valuable for the analysis to be performed. The movement of the operators is captured, analyzed and assessed in terms of how much strain a specific posture has on the human body.

### Technology readiness level



### Technology application

The technology can be used in a variety of industrial settings. Wherever there is a production line that requires a lot of repetitive motions from the individuals, monitoring of the ergonomic performance can be used to enhance safety and efficiency.

### Technology provider

ARMINES - MINES ParisTech

[www.armines.net](http://www.armines.net)  
[www.mines-paristech.fr](http://www.mines-paristech.fr)

### Target market

Ergonomists  
and industrial  
engineers



## Robot self-learning and multimodal learning

Robot learning and self-improvement of assembly tasks with AI. The robot has the capability to autonomously improve the policy given the specified criteria. *Furthermore, the robot can gradually learn strategies to resolve from unforeseen situation and return into normal mode of operation.* This solution requires external sensors such as force/torque sensors and vision sensors. It is a basic enabling technology for faster more efficient robot exploitation that can be applied to the majority of collaborative robots.

The technology is intuitive enough so that the user can teach a robot various tasks without having high expertise. This solution enables to spend less time on robot programming, as the robot tasks will be optimized during the exploitation. No training is required for the final user.



### Technical requirements

This is a software component, which can either run on an external computer or the robot controller itself. Installation of this component requires highly trained personnel and heavily depends on the robot and the type of application.

### Technology application

Any robot tasks, where the users would like to optimize the performance.

### Target market

Industries  
SMEs

### Technology readiness level



### Technology provider

Jožef Stefan Institute & CERTH

[www.ijs.si](http://www.ijs.si)  
[www.certh.gr](http://www.certh.gr)







## Sensorized robotic skin

The robot skin technology allows to process contact distributions occurring on large areas. The system is based on an interconnected network of sensors relying on capacitive technology. Each sensor has a specific number of triangular shaped capacitive taxels which are supported by a flexible substrate. Communication ports placed along the sides of each sensor sides allow communication with adjacent sensors. The robot skin is modular, compact by design and can conform and be deployed on non-flat and smooth curved surfaces.

In the CoLLaboratE project, a set of handles pertaining to a windshield handling gripper are sensorized with robot skin to provide a tactile interface that can be used by the operator to physically interact with the robot.



### Technical requirements

The technology involves both hardware and software component making it a single entity.

### Technology application

The technology is directed towards tactile feedback sensing applications such as human contact recognition, robotic grasping, and contact detection in industrial, robotics and research settings.

### Target market

Industries  
SMEs

### Technology readiness level



### Technology provider

University of Genoa

[www.unige.it](http://www.unige.it)



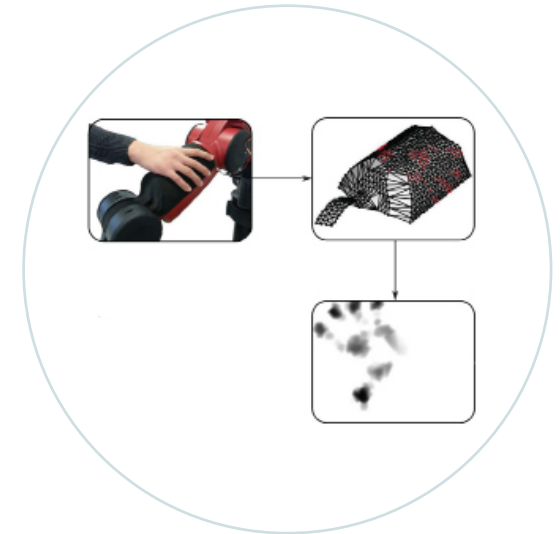




## Human touch recognition

The enabling component for the human-touch and classification is based on the robot skin technology. Tactile data gathered from the robot skin are converted into an image that encodes the pressure distribution applied during a contact. Machine learning-based approaches are then used to recognize the contact shape generated by a human operator touching the sensorized area with her/his hand.

Within the CoLLaboratE project, this recognition is performed when the operator interacts with the sensorized gripper. This is useful to discriminate between voluntary physical interactions and generic collisions. As an outcome, if a human hand contact is classified, the operator will be allowed to manually move the robot.



### Technical requirements

A deployed and functional robot skin is required.

### Technology application

Suitable application scenarios would be in cooperative and collaborative operations between human and robots in industries.

### Target market

Industries  
SMEs

### Technology readiness level



### Technology provider

University of Genoa

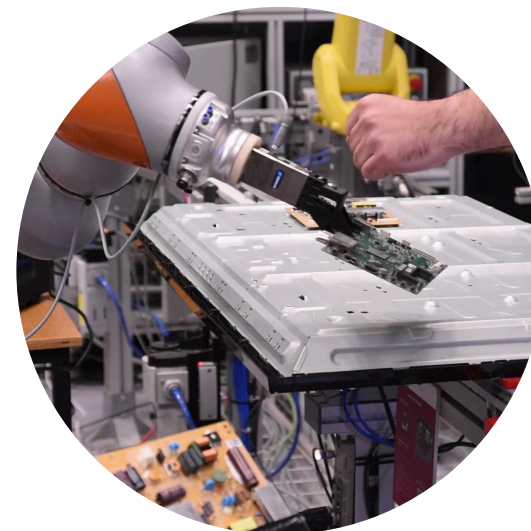
[www.unige.it](http://www.unige.it)





## Dynamic active constraints

This technology achieves safety of the human operator when he/she shares the workspace with an autonomous robotic manipulator. The method reshapes the robot's trajectory in order to avoid dynamic obstacles such as the human body, which is recognized online with skeleton tracking methods.



### Technical requirements

The method requires a kinematically controlled robot and a skeleton tracking method (e.g. through vision) that constructs online the forbidden areas, which are then provided as input to the developed software for dynamic active constraints enforcement.

### Technology application

This technology is suitable for any task where the robot operates autonomously in dynamic environments and needs to avoid obstacles.

### Target market

Industries  
SMEs

### Technology readiness level



### Technology provider

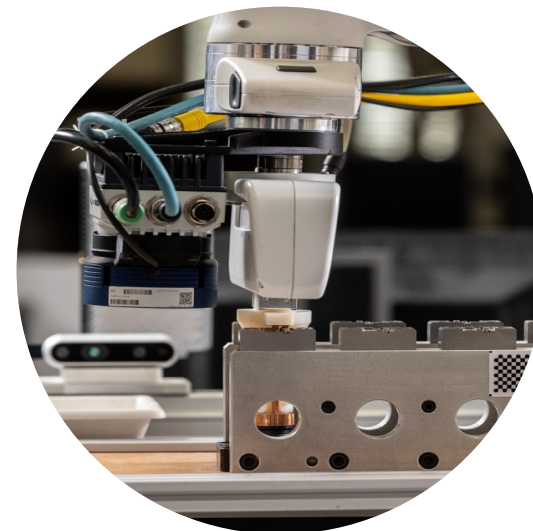
Aristotle University of Thessaloniki /  
Automation and Robotics Lab & CERTH

[arl.ee.auth.gr](http://arl.ee.auth.gr)  
[www.certh.gr](http://www.certh.gr)



## Exception Strategies Learning

In industrial assembly, errors can occur due to stochastic reasons even when the policy has been carefully prepared. Human intervention is usually required in such cases. JSI developed a framework where such interventions are associated with current multimodal sensor information (called context) and stored in a database of past experience. Next time an error occurs, the robot synthesizes new action based on the current context and past experience using statistical learning. Eventually, it autonomously resolves errors as they occur.



### Technical requirements

This technology does not require redesigning the production line but requires additional sensors according to the specific use case requirements.

### Technology application

Most of assembly lines that apply robots

### Target market

Industries

### Technology readiness level



### Technology provider

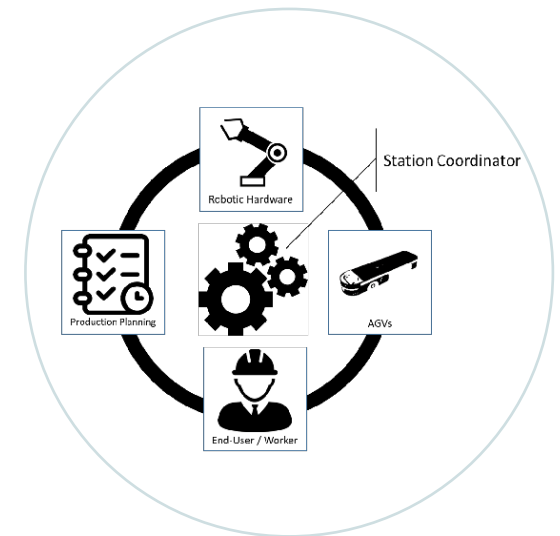
Jožef Stefan Institute

[www.ijs.si](http://www.ijs.si)



## Production Planning Module

A human-robot collaboration planning system that will optimally utilize the available production resources and orchestrate the coordination of the processes within a production line. The implementation of a Decision Support System will allocate the collaborative tasks to production resources.



### Technical requirements

Installation of the technology requires adaptation to the new process model and no modification to the existing hardware. Additional hardware adapters must be implemented for the existing hardware.

### Technology application

Any assembly production line requires collaborative tasks to be detailed.

### Target market

Industries  
SMEs

### Technology readiness level



### Technology provider

Laboratory for Manufacturing Systems &  
Automation  
[www.lms.mech.upatras.gr](http://www.lms.mech.upatras.gr)

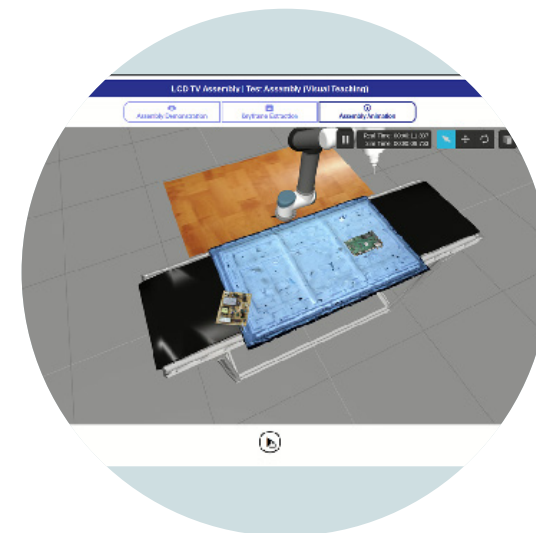




## Human-in-the-loop HMI interface

The developed technology allows intuitive interaction between human workers and the robotic system. No special training is required for the users, since it is a user-friendly graphical user interaction interface designed and developed specifically for Human Robot Interaction applications.

It is web-based following a client-server architecture and it can be deployed even on portable devices, such as PC Tablets and/or smartphones. It can be utilized to guide a visual or kinesthetic teaching session, or to manage the production line, depending on which users are signing in.



### Technical requirements

An external computer is required to act as the server for the web-based GUI, whereas a PC Tablet is required for interacting with the system throughout the demonstration via the GUI acting as the web client. A Wi-Fi connection should be available for connecting the client to the server. Robot Operating System (ROS) and Gazebo simulation platform should be installed on the server PC.

### Technology readiness level



### Technology application

Human Robot Interaction (Intuitive, user-friendly interface).

### Target market

Industries / SMEs utilizing robotic agents that require interaction with humans.

### Technology provider

Centre for Research and Technology Hellas (CERTH) / Information Technologies

[www.certh.gr](http://www.certh.gr)  
[www.iti.gr](http://www.iti.gr)



# Use cases

## Introduction to the use cases:

---

The CoLLaborate project is not developing one single robot for a specific purpose, but rather interconnected software modules that facilitate genuine collaboration between robots and humans. We have chosen 4 use cases with very different types of assembly tasks to show the variety of applications of the CoLLaborate system.

Even though these use cases are based on different hardware components, the CoLLaborate system can be adapted with just a few software modifications. Manufacturing companies can easily program assembly tasks and flexibly adapt to changes in the production pipeline.

Our early adopters are Kolektor Orodjarna, Centro Ricerche FIAT SCPA, Romaero SA and Arçelik A.Ş.

**KOLEKTOR**



**Arçelik**

**ROMAERO**

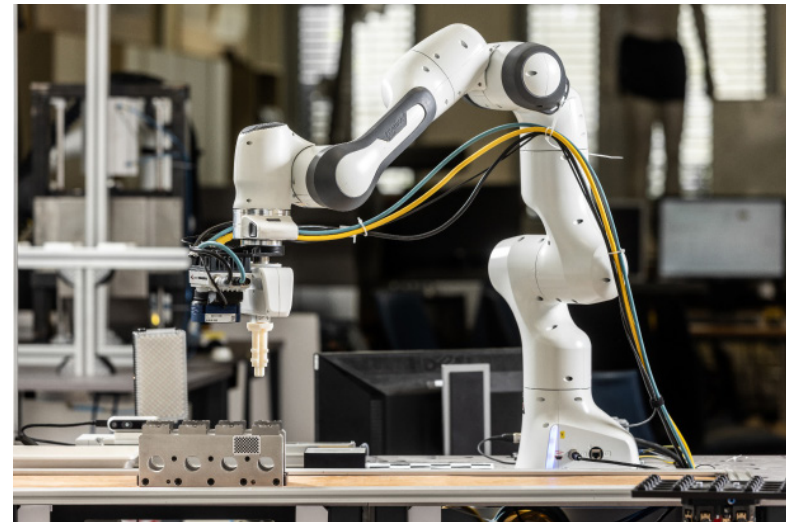


# Use cases

## Use-case 1: Car starter assembly

The vision of the project was to develop a robotic system able to assist or even replace the worker when he/she is not present at the workcell. The results of CoLLaboratE support employees giving them more time to focus on more essential tasks such as: troubleshooting production lines and some unforeseen shutdowns. Moreover, while working with the collaborative system they can do it safely and efficiently. Inserting copper sliding rings into these installations, in particular, is a laborious task that no one likes to do.

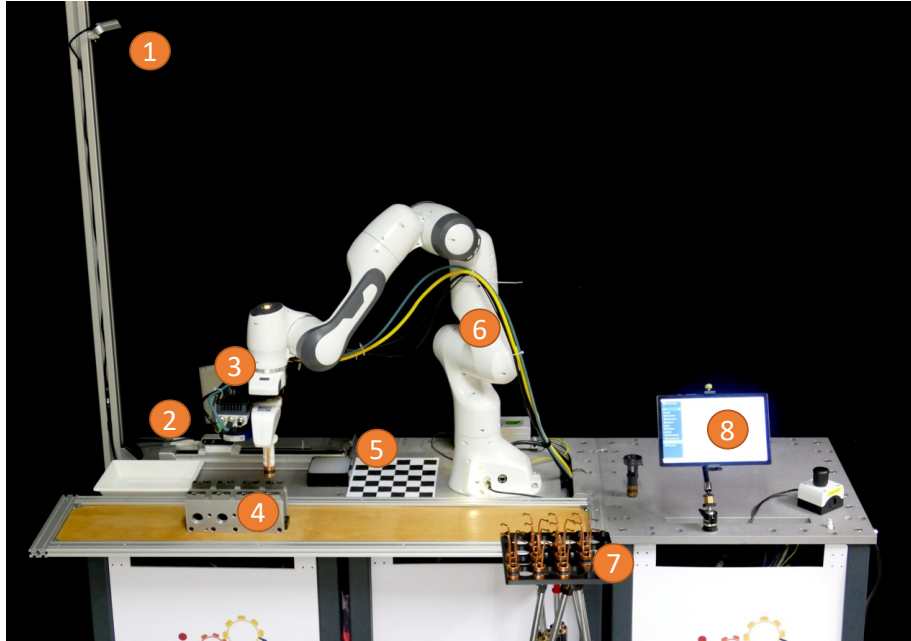
In a modern production environment, human operators tend to work with more than one production line and more than one production machine. That is why they are less likely to cooperate with robots full time. Our production lines have as little as possible manual workstations. The worker and the robot must be able to execute the same tasks where the work is assigned dynamically with the emphasis on safety, they need to complement each other. For this reason, multiple approaches and technologies were developed and used to facilitate the functionality that to a certain extent mimics how the worker acts and reacts to different situations.





# Use cases

## Use-case 1: Car starter assembly



1. Overhead RGBD camera for **human motion tracking and intention prediction**
2. Linear drive with assembly control camera and adaptive light panel for **context determination**
3. In-hand camera for **visual inspection**
4. Molding fixture
5. Backlight station for ring **orientation check**
6. Collaborative robot equipped with ATI force sensor
7. Passive reconfigurable fixture that adapts to **workers ergonomics**
8. Tablet for **HRI**

There are two key technologies exploited to make human robot collaboration possible. The first is robot compliance, unlike the standard industrial robot, which is rigid all the time, a collaborative robot must change its compliance from being completely rigid to completely compliant. The second is that the robots are aware of the human presence in the worksite and robots need to predict the human intentions and need to recognize the human actions.

All these technologies become visible using agility cameras and latest technologies of neural networking like recurrent neural networks. In summary, the development efforts in this project advanced our skills to approach this and similar projects in the future.





### KEY PERFORMANCE INDICATOR

### RESULTS

KPI5	Autonomous Exploration and Learning of Assembly Tasks	Success rate increase of assembly execution (19%, from 79% was increased to 98%)
KPI6	Multimodal Data Acquisition, Processing, and Learning	Success rate increase wrt single modality approaches (10.7% wrt visual, 17.8% wrt F/T)
KPI9	Autonomous Policy Improvement of Assembly Task	No significant success rate increase of assembly execution but the improved policy resulted to 10% reduction of the Cycle Time
KPI13	Reduction of Cycle Time of Production	Average time of autonomous execution (picking copper rings, robot arm motion, insertion) 10 seconds, success rate 79% with exception strategy average time rises to 30 seconds but success rate increases to 98% manual performance is about 12 seconds a reduction of about 16.7% has been achieved in case no exception occurs



# Use cases

## Use-case 1: Car starter assembly

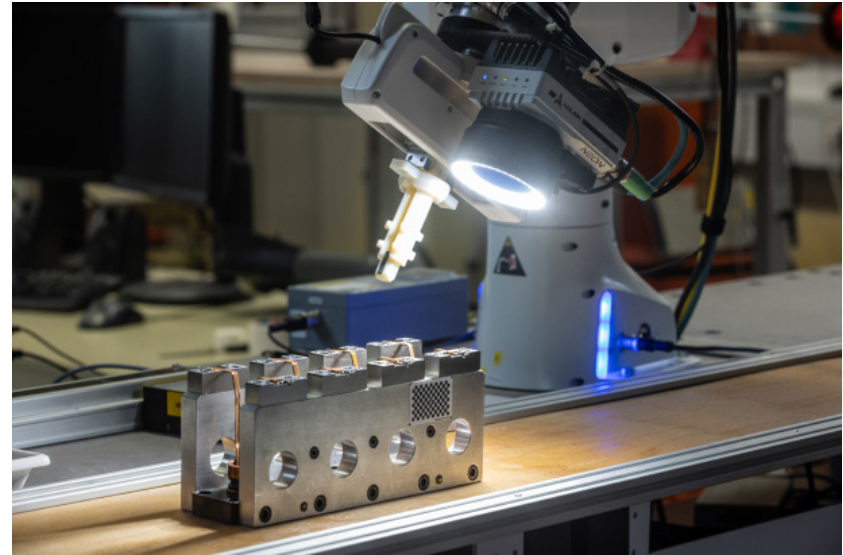
### WORKFLOW

STEP	ACTION FOR ROBOT	ACTION FOR OPERATOR
1	/	Registration using a tablet
2	Reconfigure input tray fixture	/
3	/	Filling the input tray, press the start button when ready
4	Picking up the copper sliding ring from the tray	Can perform this action in parallel by picking up the copper sliding ring from a separate tray or not at all
5	Define orientation on the backlight station and re-grasp if needed	
6	Only on the first cycle for the fixture, Register fixture position	
7	Move into insertion position	Operator can perform insertion tasks in parallel with the robot
8	Insert the copper sliding ring	Operators can perform insertion tasks in parallel with the robot
9	Inspect for correct insertion of the sliding ring part (bottom) with an RGBD camera	/
10	Move to pick position and repeat step no. 4-9 until the fixture is full	Operators can perform insertion tasks in parallel with the robot
11	Inspect the insertion correctness of the copper contacts with the RGB Camera	/
12	Repeat steps 4-11 until there are no more parts on the input tray	/
13	If the tray is empty at this point and there are no other tasks the robot waits for user confirmation that the tray is ready	Preparing a full tray for the collaborative system to use and confirm by pressing the start button



# Use cases

## Use-case 1: Car starter assembly



*«In a modern production environment such as ours, human operators normally tend to work with more than one production line and more than one production machine. That is why they are less likely to cooperate with robots full time. Our production lines have as little as possible manual workstations. The worker and the robot must be able to execute the same tasks where the work is assigned dynamically with the emphasis on safety, they need to complement each other. For this reason, multiple approaches and technologies were developed and used to facilitate the functionality that to a certain extent mimics how the worker acts and reacts to different situations.»*

Jure Skrabar -

Researcher Optical Metrology at Kolektor Vision

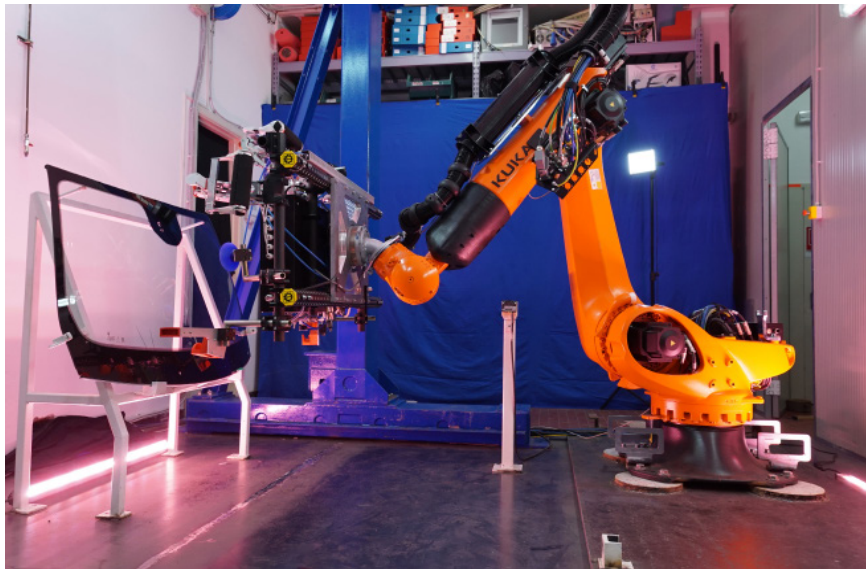




# Use cases

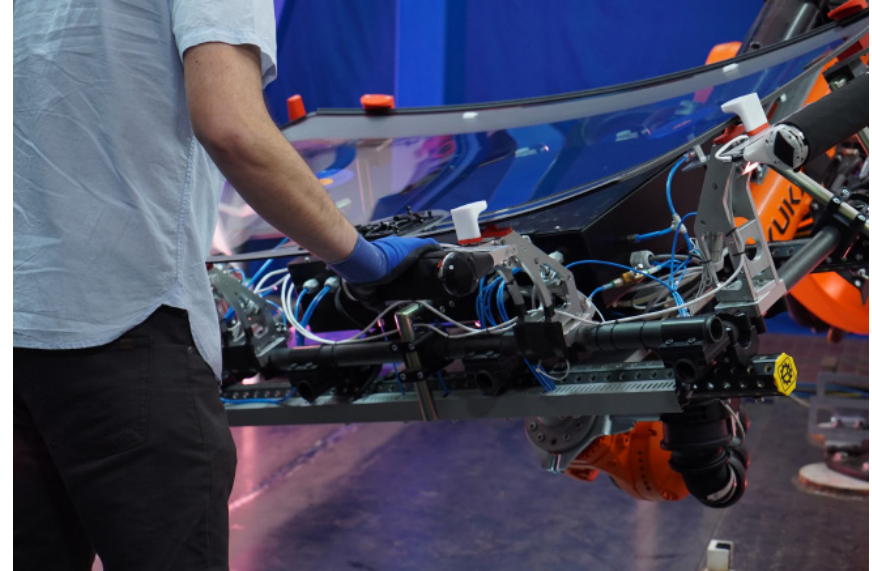
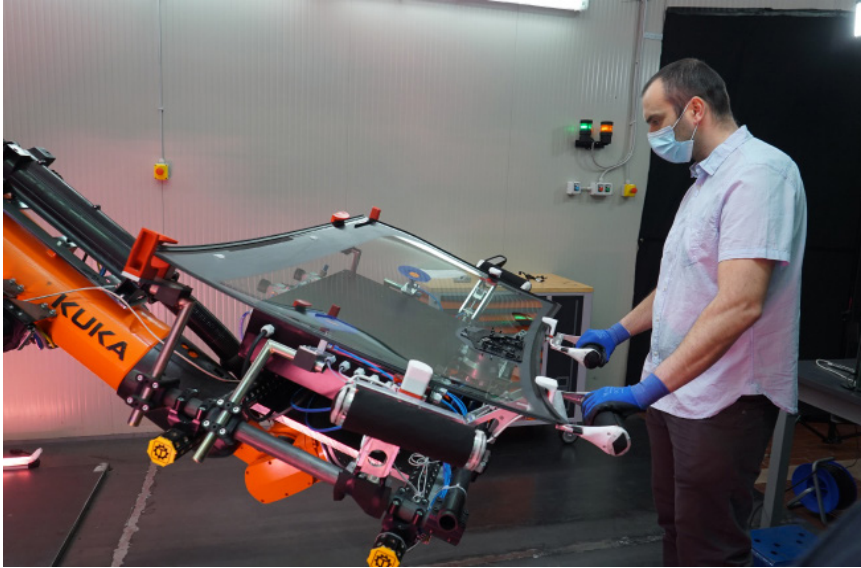
## Use-case 2: Windshield assembly & inspection

Challenge 2 addresses Human-Robot Collaboration (HRC) to simplify a visual quality check and perform a phase of manual assembly of the windshield before it is assembled on the car chassis. The robot automatically picks up a windshield from the plant logistics, brings the windshield to an operator and collaborates with the operator while the operator mounts the rear mirror, sensors and cabling on the windshield and checks for cracks or defects. The robot will then assemble autonomously the windshield on the car chassis. The proposed system simplifies the workcell, minimizes work cell area, reduces lead time and specifically learns to personalize operator preferences based on good ergonomics. The robot and the operator interacts through tactile sensorized handles using several of the collaborative modules developed in the project.



# Use cases

## Use-case 2: Windshield assembly & inspection



The core development of Challenge 2 is focused on the Hand Guiding operations enabled by the interaction between the robot and the advanced gripper by UNIGE while taking into consideration the safety logics beyond the application. In Challenge 2, three functionalities developed within this project are integrated successfully:

- 1) Sensorized skin handles: Sensorized handles capable of sensing the operator's touch, recognizing the shape of the touch zone.
- 2) Classification of voluntary/involuntary interaction by the worker through the skin.
- 3) Robot adaptive control for heavy object manipulation.



### KEY PERFORMANCE INDICATOR

### RESULTS

KPI2 Human Touch Recognition and Classification

Successful human touch recognition and classification with a frame rate of 20 Hz

KPI13 Reduction of Cycle Time of Production

The use of CoLLaboratE HRC technologies and the redesign of the workcell enabled by the CoLLaboratE application, enabled a very important Cycle Time reduction: -27% with respect to the same application without Human Robot Collaboration





# Use cases

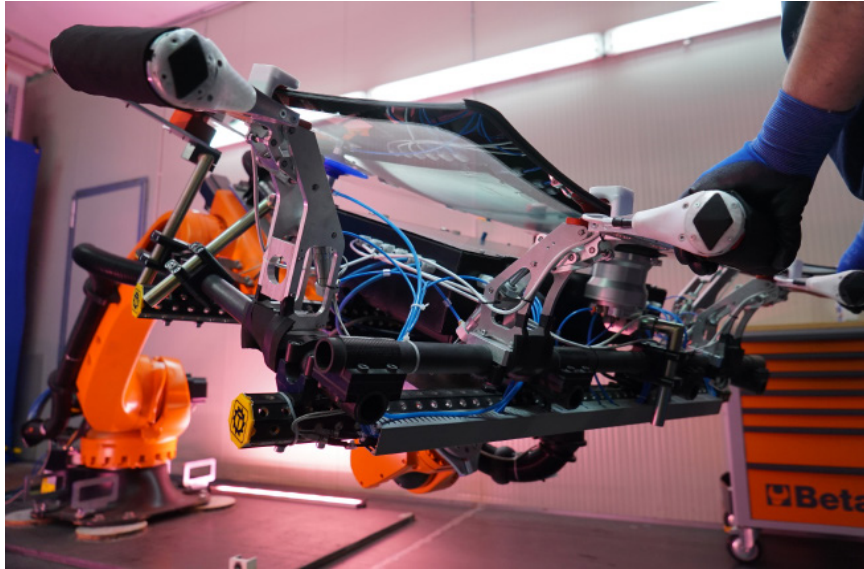
## Use-case 2: Windshield assembly & inspection

WORKFLOW		
STEP	ACTION FOR ROBOT	ACTION FOR OPERATOR
1	<ul style="list-style-type: none"> <li>a. Pick up the windshield from the rack</li> <li>b. It moves into a grouped position</li> <li>c. It rotates the gripper towards the operator's work area</li> <li>d. It waits for the user to press the 'Start Collaborative Phase' button</li> </ul>	<ul style="list-style-type: none"> <li>a. Performs other operations in the cell while remaining outside the "risk" areas</li> <li>b. Toggles the 'Start Collaborative Phase' button when the robot is near the collaborative area</li> </ul>
2	<ul style="list-style-type: none"> <li>a. From the grouped position the robot stretches up to the operational area of the operator</li> </ul>	<ul style="list-style-type: none"> <li>a. Approaches the gripper from the front direction without violating the red zone</li> </ul>
3	<ul style="list-style-type: none"> <li>a. Hand-guided behavior by variable admittance control, exploiting the touch-based sensing architecture and the F/T flange sensor</li> </ul>	<ul style="list-style-type: none"> <li>a. Performs crack/defect inspection on the windshield by grasping the handles and guiding the robot, adjusting the orientation to exploit the environmental light to detect cracks</li> <li>b. Proceeds to mount the lane detection sensor and the rearview mirror, moving the robot to find the most suitable position for each part of the assembly</li> <li>c. Releases the handles and pushes the 'End Collaborative Phase' button</li> </ul>
4	<ul style="list-style-type: none"> <li>a. The robot moves back to the grouped position and then towards the rack to release the windshield</li> <li>b. Returns to the initial position</li> </ul>	<ul style="list-style-type: none"> <li>a. The operator completes his cycle and returns to the logistics for further tasks or next operation</li> </ul>



# Use cases

## Use-case 2: Windshield assembly & inspection



«Human robot collaboration brings many benefits. There are benefits in term of cost of installation because there is a simplification of the work cell and there is a reduction or removal of the fences that otherwise would be needed in order to ensure the safety to separate the human from the robot. There are benefits in terms of productivity because it is possible to assign to the robot those non value added activities that otherwise would take time from the operator. There are benefits in terms of safety and ergonomics: safety because the overall safety is ensured by the robot, the cameras and the controller, that are above; ergonomics, since the robot enables a clever positioning of the tool ensuring the best ergonomics for the operator.»

Alessandro Zanella - Centro Ricerche FIAT, Stellantis





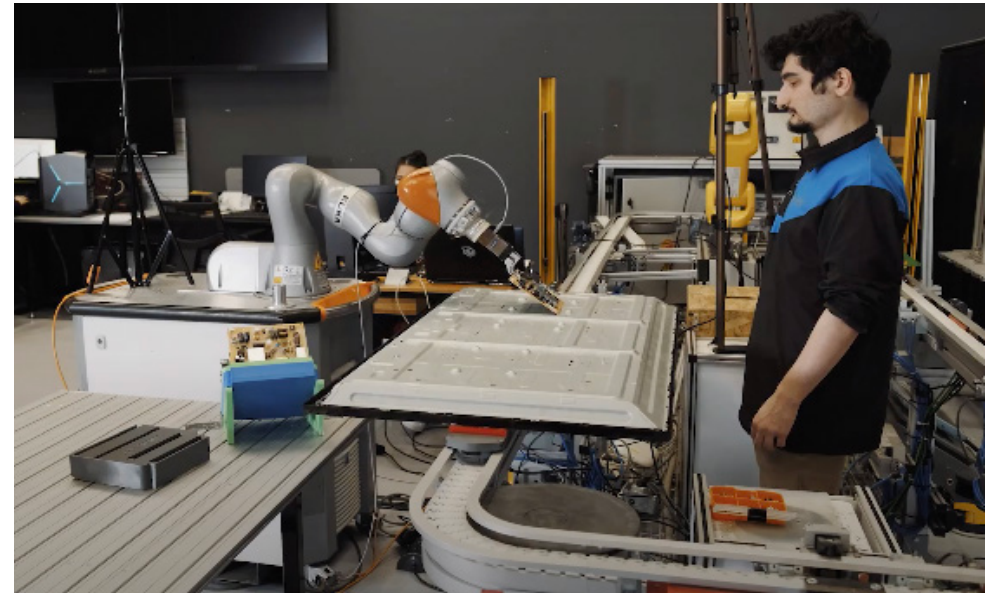
# Use cases

## Use-case 3: LCD TV assembly

Challenge 3 focused electronic card assembly operation in LCD TV assembly. New technologies require the industry to produce new and more advanced models, resulting in adding at least one new model to production each month.

The placement of TV chassis and PSU cards change with each model, making it impossible to automate this process using traditional methods. Considering the new model frequency in the production line, hiring an engineer to go and program the robot whenever a new model comes makes this task very costly. As a result, assembly of electronic cards in LCD TV production is done with two operators 100% manually. Picking and placing cards for TV assembly contains a lot of repetitive movements, making this process ergonomically risky in the long run.

In the CoLLaboratE system, teaching by demonstration is used to tell the robot where and how the cards will be placed, making the programming process possible for everyone. With being able to teach by human demonstration we increase the participation of operators in the production process and reduce engineer costs. With the collaborative cell designed for this use case, most of the repetitive tasks are taken by the robot, increasing the ergonomics of this process. CoLLaboratE proves that collaborative robots can be used in shop floor when given the opportunity. The developed collaborative cell for LCD TV assembly use case has made it possible to automate electronic card assembly operation and significantly increased the ergonomics of the operators. The final demonstrator can learn from human demonstration, do conveyor tracking to pick and place the cards, avoid collision with the operator and communicate with the operator using gestures.

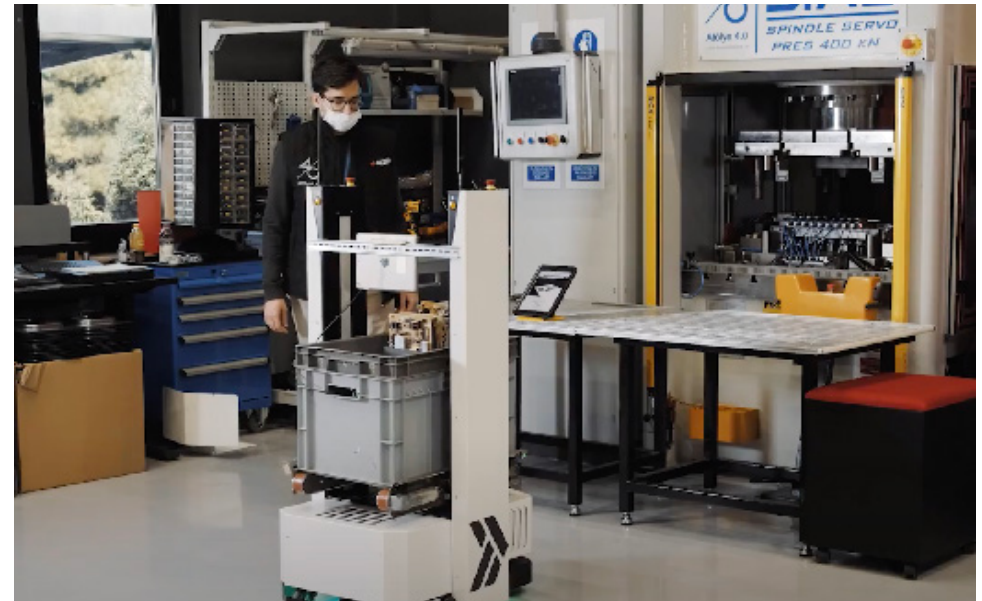


# Use cases

## Use-case 3: LCD TV assembly

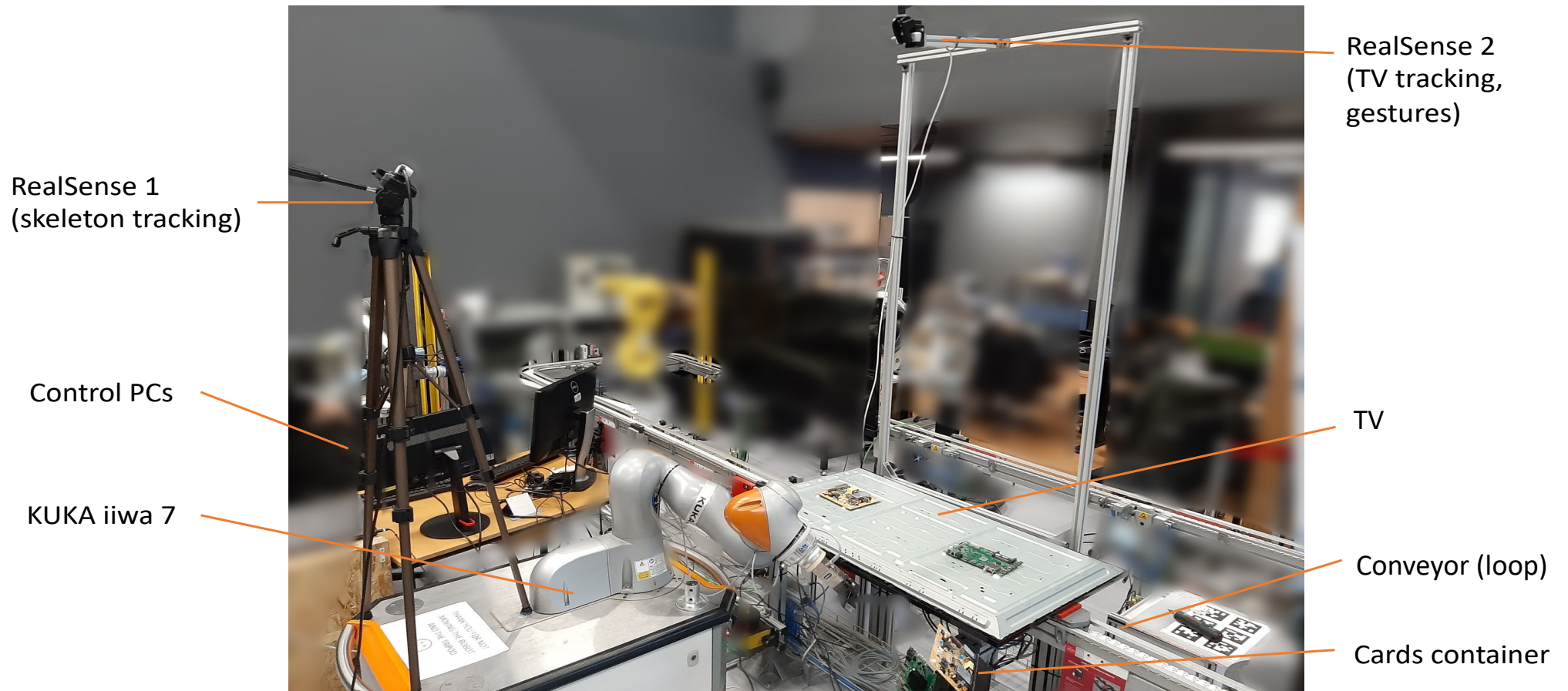
To integrate this system to the production line, a stable non-vibrating skeleton is needed on top of the conveyor to place the RGBD camera for TV detection and gesture recognition modules. In addition, a stable tripod or other alternative is needed for the RGBD camera used for safety constraints. One point to keep in mind is the robot placement, the robot should not be too far from the conveyor in order to avoid singularities. Two PCs with NVIDIA GPU cards is important for the system to work properly is essential. All the PCs used for the system must be in the same network for them to communicate, IP configurations must be done when setting up the system. For the AGV part, only a mapping should be done of the area AGV will be working on, other than that marking the charging station, marketplace and production station in the AGV software is enough.

In the final setup, one RGBD camera is used on top the TV for TV detection and recording card placement information. This camera is also used for gesture control modules. Another RGBD camera is setup behind the robot for safety constraint implementations and avoid collision between the operator and robot. As the collaborative robot, KUKA Iwaas R800 has been used. It has been selected due its flexibility and ease of programming. Multiple control PCs are used to implement the modules smoothly. In addition to the two RGBD cameras there is one RGBD camera on the AGV to implement gesture control on the AGV.



# Use cases

## Use-case 3: LCD TV assembly





### KEY PERFORMANCE INDICATOR

### RESULTS

KPI1	Real-time human skeleton tracking for safety constraints	Tracking rate (30Hz)
KPI3	Human gesture recognition	Recognition accuracy (>90%)
KPI10	Real-time HRI Response	Delay of interaction <100 ms (Instant response)
KPI13	Reduction of Cycle Time of Production	During testing the speed of the conveyor belt was set to about 3 cm/sec similar to the actual production the execution was performed at 115% of the speed of the kinesthetic demonstration yielding a total average cycle time was equal to 58 seconds (25 seconds for placing the PCBs and 33 seconds for grasping/picking them), which is significantly larger with respect to the existing solution – 17.4 seconds rescaling of the duration of learned task more than 115% is possible but further investigation is necessary to verify the safety and efficiency of such approach



# Use cases

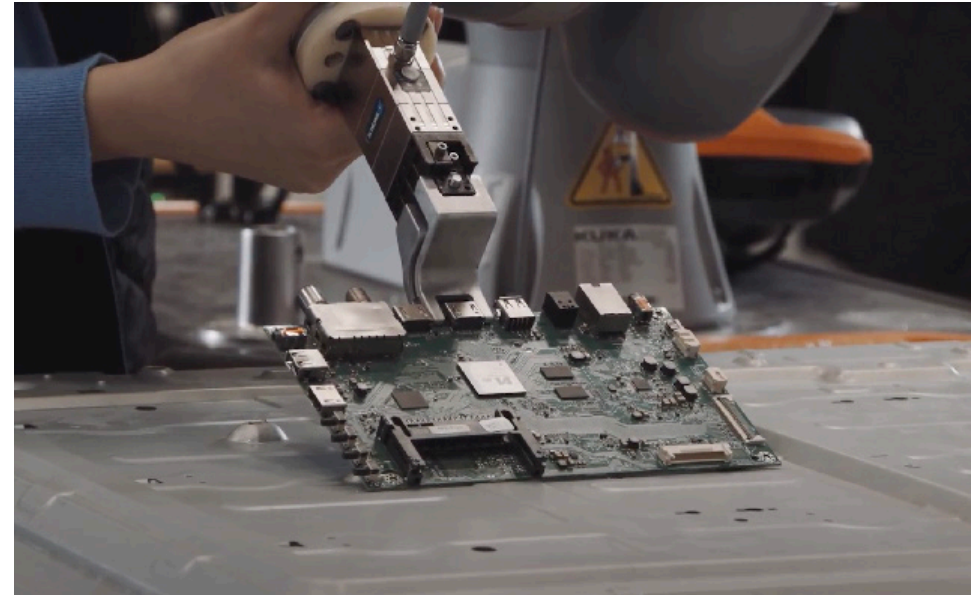
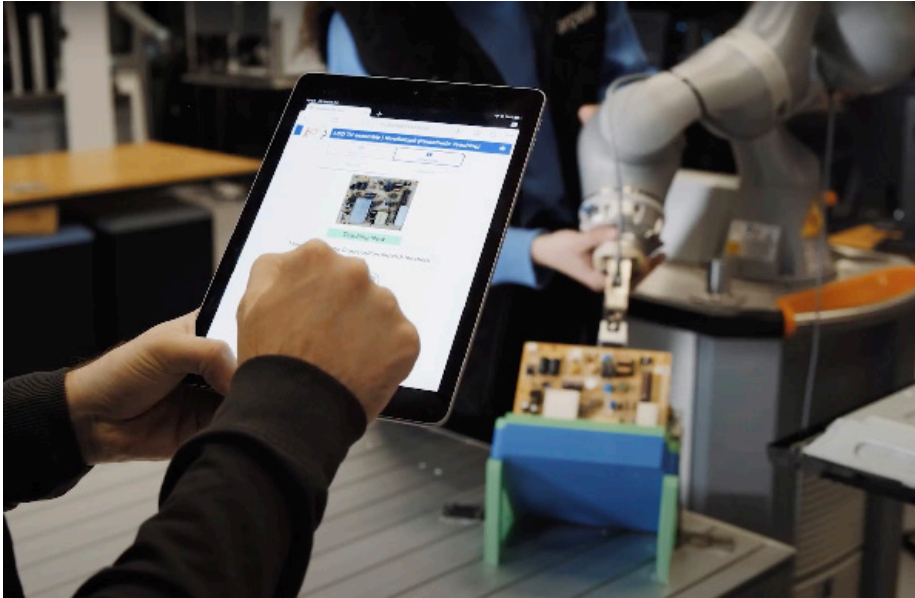
## Use-case 3: LCD TV assembly

WORKFLOW		
STEP	ACTION FOR ROBOT	ACTION FOR OPERATOR
1	Grasp a PSU card inside the box, bring the card towards the TV	Takes the screwdriver
2	Place the PSU on its dedicated place on the TV	/
3	Grasps the PCB card inside the box	Starts to screw 4 screws on the PSU card
4	Brings the PCB towards the TV Places the PCB on its dedicated place on the TV	Continues the screwing process Continues the screwing process
5	/	Starts screwing as soon as the previous one finishes



# Use cases

## Use-case 3: LCD TV assembly



«In conventional methods we need robotics experts to these adjustments all the time. Thanks to the technologies developed by the CoLLaboratE project and the collaborative robotic cell, we don't need the experts anymore. Both the engineers and operators on the line are working safely with the robots and they are no longer afraid of robotic systems. I think this will increase the adaptation of robotic systems in production in the future.»

**Turgut Köksal Yalçın**

Manager - Industrial Robotics at Arcelik



# Use cases

## Use-case 4: Aerospace structure riveting

Challenge 4 pertains to the assembly of aeronautical structures by riveting. Percussive riveting is a process difficult to automate, involving two human workers. Two or more structural components are assembled together by the plastic deformation of a metallic rivet. The rivet is deformed by means of repeated mechanical shocks with relatively high frequency. Given the complexities of the structures to be riveted, the body postures of the workers (in particular the worker holding the bucking bar) are highly uncomfortable, leading to potential long term health consequences.



The robotic system developed in Challenge 4 works in close collaboration with a human operator, which leads the process and always verifies the quality of the riveting. The communication within human-robotic system is accomplished by means of an interface, by voice and by gestures. The robotic system is composed of a variety of sub-systems like: 6 DoF robotic arm, AGV, linear actuator, RGB and RGB-D cameras, two computers, one force-torque sensor, an arm-attached display and one router.





# Use cases

## Use-case 4: Aerospace structure riveting



The introduction of such a system in an industrial environment has multiple advantages, the most representative ones being an improvement in the ergonomics of the riveting process and an increase in productivity. The system can be easily adapted for the riveting of a variety of structures just by software update and, in some cases, minimal hardware modifications (e.g. new end effector design). As such, the system represents a long-term, versatile, easy to use industrial asset, characterized by a high added value over cost ratio.

The system can also be used for riveting in other industrial applications – e.g. naval or automotive. Moreover, it can be adapted for other collaborative assembly tasks relying on the modules developed in the CoLLaboratE project (navigation, voice/gesture control, visual recognition of geometric features, human skeleton tracking, etc).

Having been validated in a real industrial environment, the system is now characterized by a TRL 5. Further improvements and optimisations will allow it to become more reliable and efficient. Also, a fully optimised system will be capable of ensuring a quality of the riveting process at least as good as the quality of the manual riveting.



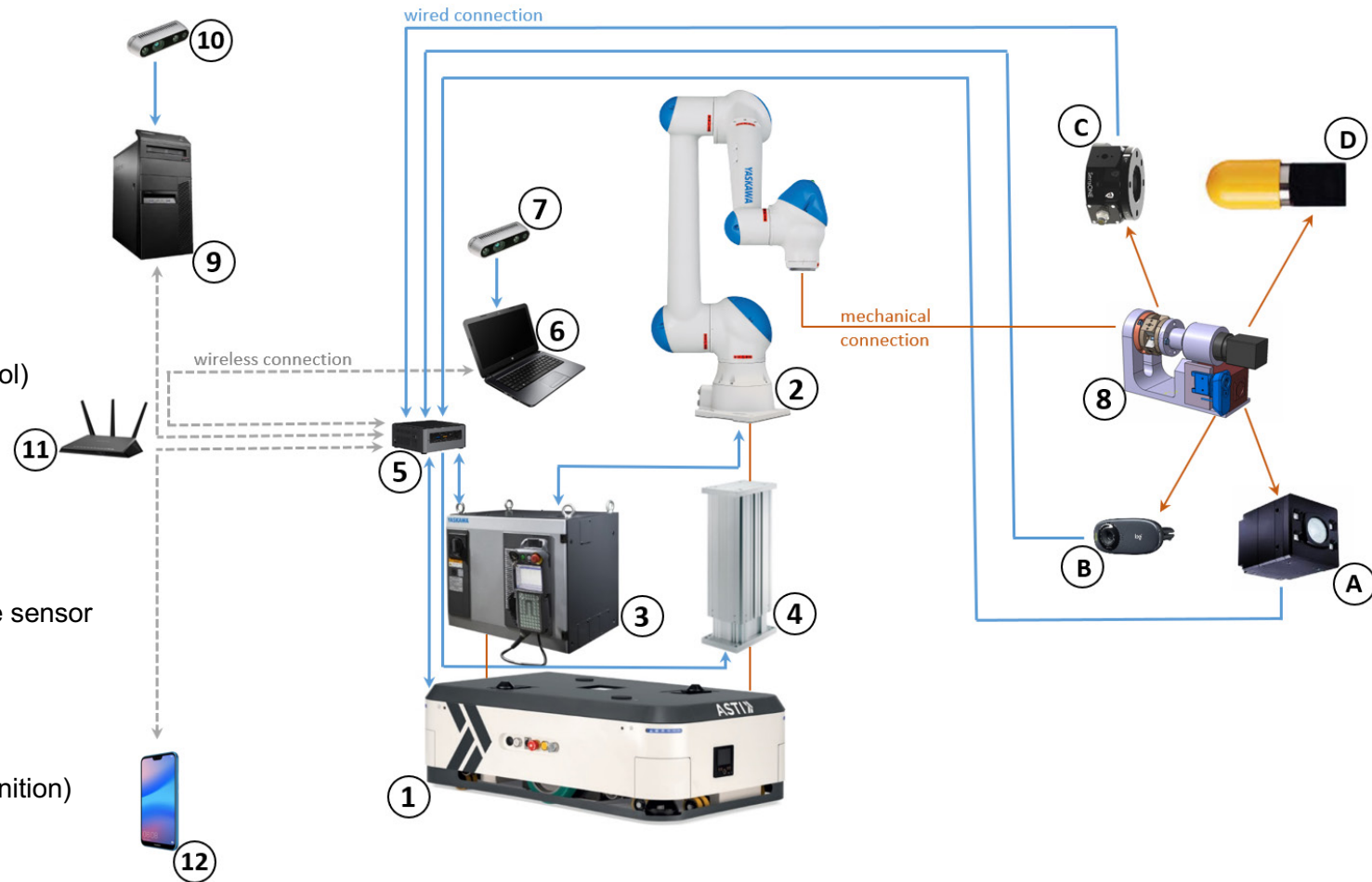


# Use cases

## Use-case 4: Aerospace structure riveting

### Hardware components:

1. AGV EBOT 350
2. Robotic arm YASKAWA HC10
3. Controller YRC1000
4. Thomson vertical actuator
5. Intel NUC computer
6. Laptop with Open Pose
7. Intel RealSense D435i camera (gesture control)
8. Customized end-effector
  - A. Lucid Helios 2 camera
  - B. Logitech C310 webcam
  - C. Bota Systems SensONE force-torque sensor
  - D. Atlas Copco damped bucking bar
9. PC (for Human Skeleton Tracking module)
10. Intel RealSense D435i camera (worker recognition)
11. Wi-fi router
12. Huawei Mate P20 Pro smartphone



### KEY PERFORMANCE INDICATOR

### RESULTS

KPI3 Human gesture recognition

Recognition accuracy (>90%)

KPI10 Real-time HRI Response

Delay of interaction <100 ms (Instant response)

KPI13 Cycle Time of Production

Numerical value: : 212/198.5 seconds/ 2 rivets. Original process - 60s for 2 rivets. Conclusion: deemed irrelevant for Use Case 4

KPI14 Quality of Collaborative Execution

Numerical value: 4 NOK out of 12 tries. Conclusion: similar quality as for the original process

KPI15 Ease of Collaborative Operation

Numerical value: 4.5/4.3 out of 5 (max). Conclusion: the system is fairly easy to use even by personnel inexperienced with robotic systems

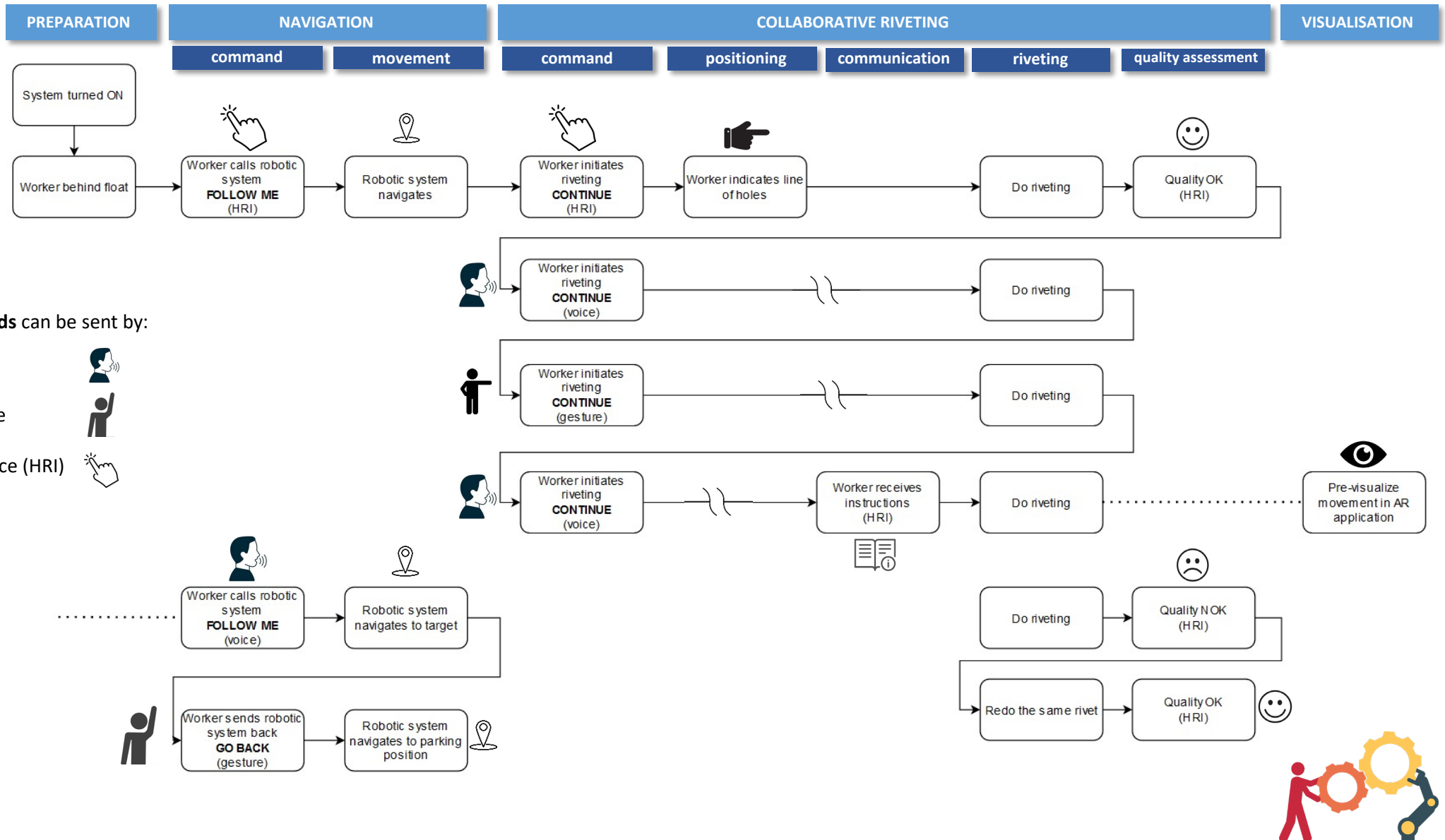
KPI16 Robot's Acceptance by Human Collaborators

Numerical value: 5/4.55 out of 5 (max). Conclusion: the technical personnel is willing to accept working with the system



# Use cases

## Use-case 4: Aerospace structure riveting



*« The robotic system developed in Challenge 4 of the CoLLaboratE project is a fully flexible system allowing collaborative riveting of different aeronautical structures, with minimal modifications. The system can thus be valorised over the course of different commercial projects, spanning 10 or more years, without any loss of performance. The main advantages of the system are an improvement in the working conditions of the human workers, together with an increase in overall productivity and also an increase in productivity per human worker.»*

**Radu Cîrligeanu**

*Research and Development Engineer – Centre for R&D and Innovation in Aerospace Technologies at Romaero SA*



# Partners



Lead partner



**KOLEKTOR**



**CERTH**  
CENTRE FOR  
RESEARCH & TECHNOLOGY  
HELLAS



**Arçelik** **ROMAERO**

**KU LEUVEN**



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 820767

## Project Coordinator

Prof. Zoe Doulgeri  
Automation & Robotics Lab  
Aristotle University of Thessaloniki  
Department of Electrical & Computer Engineering  
Thessaloniki 54124, Greece

[info@collaborate-project.eu](mailto:info@collaborate-project.eu)  
[www.collaborate-project.eu](http://www.collaborate-project.eu)



CoLLaboratE Project H2020



@collaborate\_eu