Open-Digital-Industrial and Networking pilot lines using modular components for scalable production

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Summary:

The purpose of this document is to provide the final report of developments in the ODIN core enabling technologies.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

1. EXECUTIVE SUMMARY

This document, is focused on the validation of Open Component modules inside the different small-scale pilots of ODIN. The final version of Open Component modules are presented in detail under deliverables D2.4 and D2.5. These modules cover the following aspects:

- Autonomous mobile manipulators
- Reconfigurable robot tooling
- Smart human side interfaces
- User friendly robot programming interfaces
- Robotic perception for the human
- Robotic perception for the environment and process

The validation processes of the ODIN Open Component prototype modules have taken place in several small-scale pilots, prepared at the respective technology partners' facilities. In more details, small scale pilots have been prepared at the following partners' facilities:

- LMS
- TECNALIA
- AIC
- KTH
- TAU

The safety validation activities of small-scale pilots led by PILZ are documented in the respective sections of this deliverable.

2. Introduction

One of the fundamental aspects of ODIN is the validation and integration of the core robotic technologies used for its processes before they can be deployed in industry, under an open approach. In this scope, the small-scale pilots of ODIN were designed and prepared during the progression of the project to allow the testing of the technologies developed under WP2. While the initial testing and integration of the Open Component's prototype modules was described in D2.3, further developments were conducted under the small-scale pilots in the premises of LMS, TECNALIA, AIC, KTH and TAU partners. The different Open Component modules being validated in each small-scale pilot are presented in the following table.

Table 1: ODIN Small scale pilots definition

Small Scale ID	Partner	Place	Open Component Modules
1	LMS	Greece	Reconfigurable robot tools, smart human side interfaces, robotic perception for the environment and process
2	LMS	Greece	Autonomous mobile manipulators, reconfigurable robot tools, smart human side interfaces, robotic perception for the environment and process
3	TECNALIA	Spain	Reconfigurable robot tools, autonomous mobile manipulators, robotic perception for the environment and process, user friendly robot programming interfaces
4	TECNALIA	Spain	Reconfigurable robot tools, autonomous mobile and robotic manipulators, user friendly robot programming interfaces
5	KTH	Sweden	Robotic perception for the human
6	TAU	Finland	Smart human side interfaces
7	AIC	Spain	Autonomous mobile manipulators, robotic perception for the environment and process

The final validation of the ODIN Open Component integrated in the small-scale pilots of LMS will be presented in Section 3. Following the same approach, the small-scale pilots of TECNALIA, AIC, KTH and TAU partners will be presented in Sections 4, 5, 6 and 7 accordingly.

3. LMS SMALL SCALE PILOTS

As described in D2.3, the small-scale pilots at LMS are related to the Automotive and the White Goods pilots of ODIN. More specifically, the small-scale pilots are developed in order to test and integrate the ODIN WP2 modules and more specifically the reconfigurable robot tools, the smart human side interfaces, robotic perception of the environment and process, and the autonomous mobile manipulators. The final integration and testing of the WP2 technologies which are included in the small-scale pilots at LMS premises until M36 of the project, are described in this section.

3.1. Autonomous mobile manipulators

The COMAU mobile robot (Figure 1) has been utilized to perform the autonomous quality inspection of the motor and gearbox assembly for the 3rd Operation of the Automotive case. The mobile robot has been assembled in COMAU premises and delivered to LMS premises for integration. A ROS module was developed from LMS in order to communicate with the robot and execute the necessary commands. The mobility of the robot, the robot arm's motions but also the hardware and software configuration of the robot have been tested at LMS premises. Tests were also conducted regarding the connectivity of the platform with the OpenFlow module while a RC_Visard 65 camera [1] has been installed and integrated on the mobile robot.

Figure 1: COMAU Mobile Robot

3.1.1. Mobile platform and arm testing

The integration of the COMAU mobile robot inside the automotive small scale pilot of LMS is based on its ROS driver. More specifically, a TCP/IP connection is used to transfer messages to and from the mobile platform [2] while a ROS Interface is responsible for managing the messages and redistributing them appropriately to the necessary modules. The tests have been conducted with the use of specific ROS messages from the OpenFlow module towards the mobile platform in order to perform specific movements.

The robotic arm [3] of the platform is controlled separately from the mobile platform, with a ROS driver based on several PDL2 servers installed on the controller of the robotic arm. The functionality of the robotic arm has been tested inside the Automotive operation 3 small scale pilot for the execution of the quality inspection task using a camera sensor installed on end effector of the robot.

3.1.2. Process perception module integration

An RC_Visard 65 camera is installed at the end effector of the robotic arm in order to perform the inspection process of the Automotive pilot operation 3. A custom flange has been designed and manufactured by LMS in order to install the camera on the robot (Figure 2).

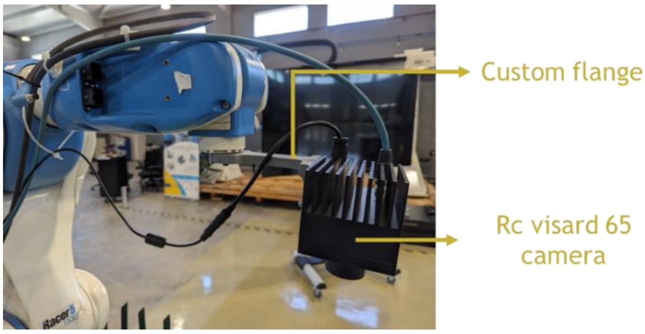


Figure 2: Installation of RC_Visard 65 on the mobile robot

The connectivity with the camera sensor has been achieved with a wired connection to an assigned router giving access for the camera to the ODIN network. The connectivity of the camera has been tested as part of the Automotive 3rd Operation where several pictures were transmitted from the camera to the inspection module.

3.2. Reconfigurable robot tooling

As part of the ODIN Open Component a selection of reconfigurable tooling options have been implemented in both LMS small-scale pilots. In this section the testing and the physical implementation of these parts is presented.

Automotive

In the Automotive small scale pilot, the focus is around the manipulation of heavy parts from the industry, specifically the pick and place of a motor (≈127kg) and a gearbox (≈107kg) provided by STELLANTIS (PSA). Tasks such as tool changing operations have also been taken into consideration when testing the tooling solutions.

The testing for motor's manipulation has been conducted with the COMAU AURA [4] robot at LMS premises, where the payload of the motor gripper (≈40kg) and the motor were taken into account. A modular end effector was developed at LMS premises and with the use of solenoid valves attached to the gripper which is also described in more detail under D2.4. The setup is visualized in the following Figure 3.

Figure 3: Motor gripper integrated with AURA robot

The motor gripper testing has been successful done in terms of grasping and lifting the motor. The operating principle of the gripper as documented in D2.4 was adequate in picking the motor, moving it and placing it again. The AURA robot is able to withstand the payload of the gripper and the motor without issues. The gripper has been tested both in terms of strength and stiffness, proving that the design is feasible for implantation in the production.

The gearbox gripper was also assembled at LMS premises and tested with the gearbox provided by PSA and the AURA robot. The setup is also visualized in the following Figure 4.

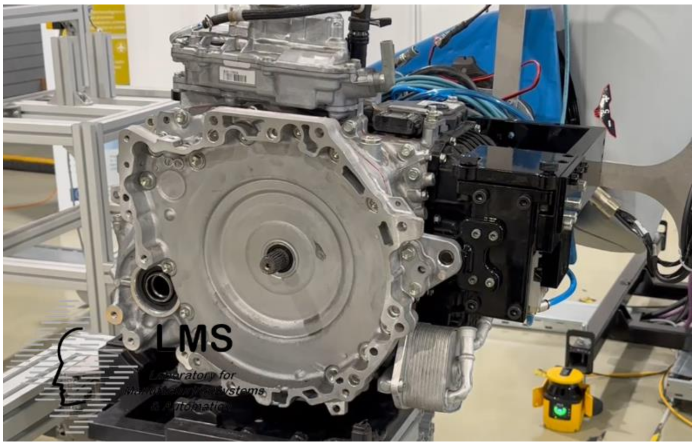


Figure 4: Gearbox gripper design and integration with AURA robot

The gearbox gripper tests have been conducted along the motor gripper tests as part of the Automotive 1st Operation. Using the developed gripper, the AURA robot is able to pick the gearbox.

Both grippers actuators' enabling and disabling is based on the integration of several safety pneumatic electrovalves. These electrovalves are installed at LMS premises and their testing has been done as part of the aforementioned tests. These tests were successful with the solution proving adequate for required tasks' execution.

<u>White Goods</u>

As presented in deliverable D2.3, under the second small scale pilot of LMS, a collaborative Universal Robot UR10 is utilized for the manipulation of several parts with different geometrical characteristics. Using a set of reconfigurable robot grippers as presented in deliverable D2.4, the selected UR10 robot [5] is able to pick and place knobs, transformers and 3 different type of cooktops.

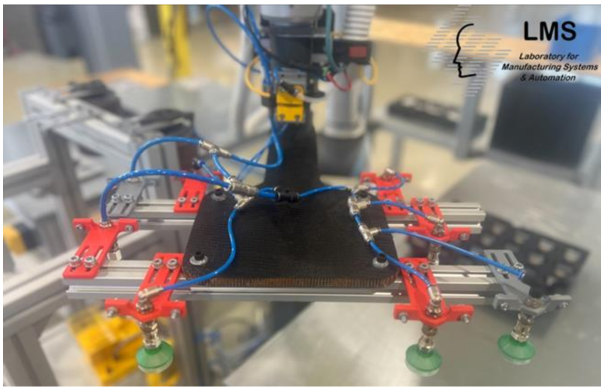


Figure 5: Vacuum gripper

As described in D2.4, a SCHUNK SMH – 36B magnetic gripper [6] and a FESTO flexible gripper [7] along with a specialized flange and tooling station have been integrated in the small scale pilot of LMS premises. Additionally, a custom vacuum gripper (Figure 5) has been assembled and is integrated in the small-scale pilot for the manipulation of cart boards but also cooktops' and knobs' blisters.

Based on the safety analysis implemented for the reconfigurable robot tools of OIDN, aluminum protective cases surrounded by soft material have been designed and implemented at the magnetic and flexible grippers (Figure 6). The vacuum gripper is equipped with a safety magnetic sensor.

Figure 6: Safety Cover for flexible gripper

The flexible and magnetic grippers have already been tested as described in D2.1. Several more tests were performed with the grippers handling all sizes of cooktops and knobs successfully. Testing with the grippers approaching the operator and releasing the parts was also performed as part of the LMS small-scale pilot.

3.3. Robotic perception for the environment, process and human

The implementation and testing of ODIN perception modules in LMS small scale pilots are presented in the following subsections of this document.

3.3.1. Object pose estimation using CAD models

As outlined in D2.3, a crucial aspect of the robotic perception essential for all three ODIN Pilot Lines is the accurate determination of the location and 3D orientation of recognized parts and components. This section provides a comprehensive documentation on the implementation of 3D pose estimation using CAD models in the LMS small-scale pilots.

3.3.1.1. Gearbox detection

The detection of the gearbox part from the Automotive pilot is investigated in the small-scale pilot of LMS. The CADMatch [8] approach is utilized as the detection method and is based on an RC_Visard 160 camera sensor and an RC_Cube [10] device. This method provides 3D object detection and pose estimation based on a CAD template created by ROBOCEPTION with the support of LMS. The requirement for this detection action is a pose prior which represents the approximate position and orientation of the part to be detected. The result of the detection process involves identifying the grasp points for the component, represented as green dots in the following illustrations. The figures below display the outcome of the gearbox part detection tests conducted at LMS premises.

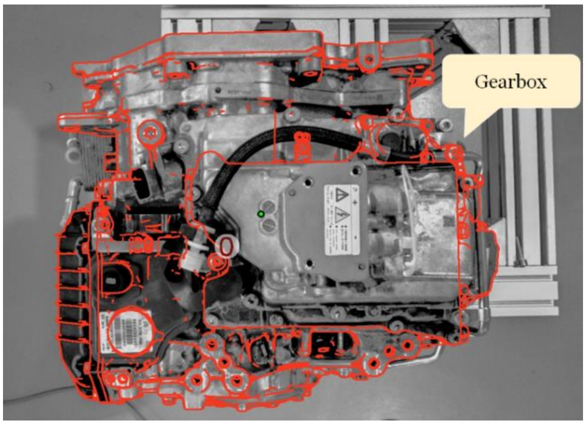


Figure 7: Gearbox detection result

3.3.1.2. Motor's lifting points detection

The detection of the motor part is based on the detection of the motor's lifting point. Within the ODIN project, testing on the acquisition of pose estimation for this points has been conducted, as it is essential for motor's manipulation by COMAU AURA robot. Following the same procedure with the gearbox detection, the pose estimation of motor's lifting point relies on the combination of RC_Visard 160 [113] camera sensor with the RC_Cube device, along with a custom template designed by ROBOCEPTION, as described in D2.4. For the optimization of the detection procedure, a predetermined pose prior has been established for the lifting point.

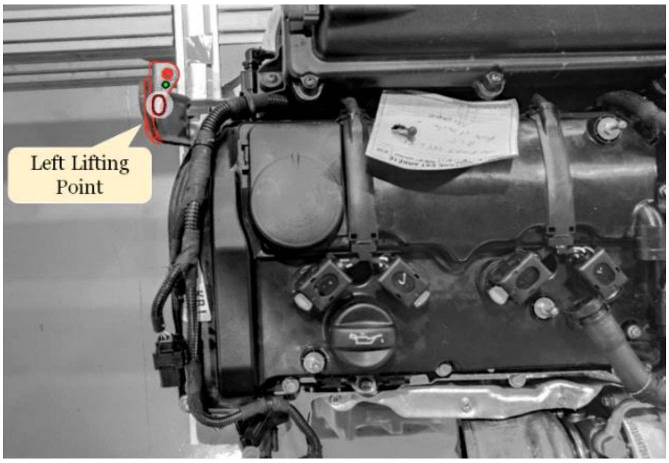


Figure 8: Motor detection result

3.3.1.3. Cooktops detection

As described in D2.3, The cooktop burner investigated in ODIN White Goods pilot consists of cooktops and knobs. These objects' detection is based on CADMatch method and a customized template developed by ROBECEPTION. Under the LMS small-scale pilot, object detection process is based on an RC_Visard 65 camera, mounted in the UR10 Cobot and an RC_Cube device. For the camera configuration, HDR mode with a gain value of 12 dB is employed. Following comprehensive experimentation, it has been observed that the accuracy of cooktop detection showed a significant improvement across all cooktop types when the background colour was adjusted to a lighter shade.

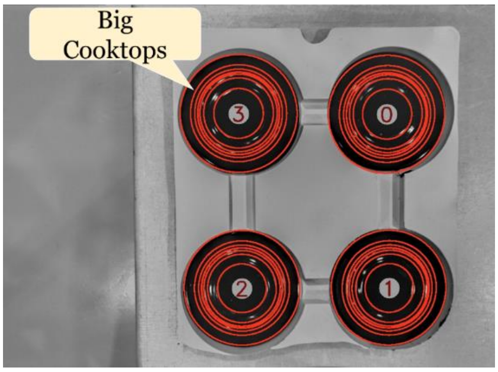


Figure 9: Detection of big cooktop parts

3.3.1.4. Knobs detection

Applying the same method and sensor setup for cooktop parts, the detection of knobs relies on the RC_Visard 65 camera working in tandem with RC_Cube and a customized template created by ROBECEPTION. Knobs' detection in the small-scale pilot of LMS is presented in the following figure.

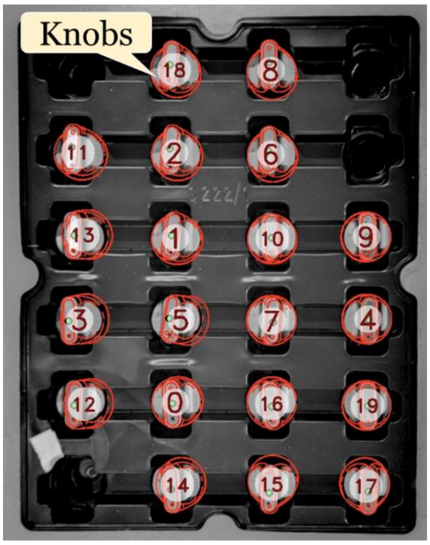


Figure 10: Detection of knobs parts

3.3.1.5. Transformer detection

Under ODIN White Goods pilot scenario, the assembly of an electrical oven is investigated. This assembly operation requires the installation of a transformer onto the oven. This process requires the pose estimation of the transformer component in order to be grasped by the cobot. This detection operation employs SilhouetteMatch [8] approach and a custom template created by ROBECEPTION. During the calibration process, the plane reference and the 2D Region of Interest have been established. The preprocessing and the execution of this detection procedure are depicted below.

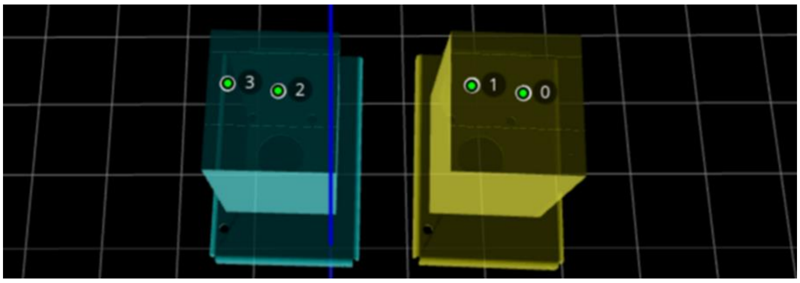


Figure 11: Custom 3D template of transformer component

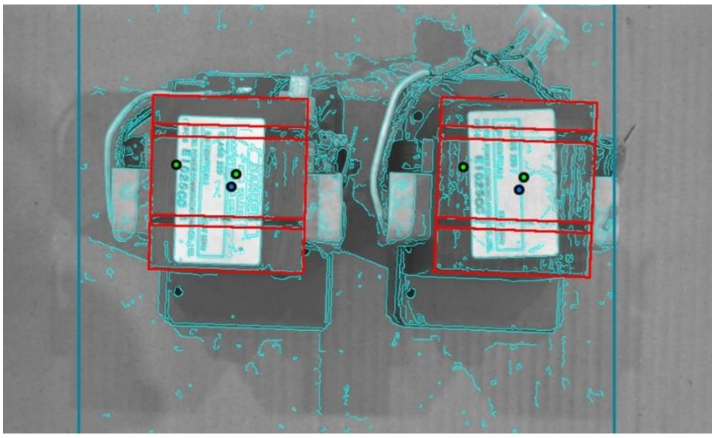


Figure 12: Detection of transformer parts

3.3.2. Quality Check

The quality inspection module developed by ROBOCEPTION with the support of LMS has been tested in the small-scale pilot of LMS. Each component under inspection is trained with HALCON DL Toolkit software [12]. This service provides data regarding both the classification and the status of the inspected components, achieved through predefined regions of interest. The results of the module's execution are visualized in the following figure. The green bounding boxes represent well-assembled parts, while the red ones indicate poorly assembled parts that will necessitate human operator intervention.

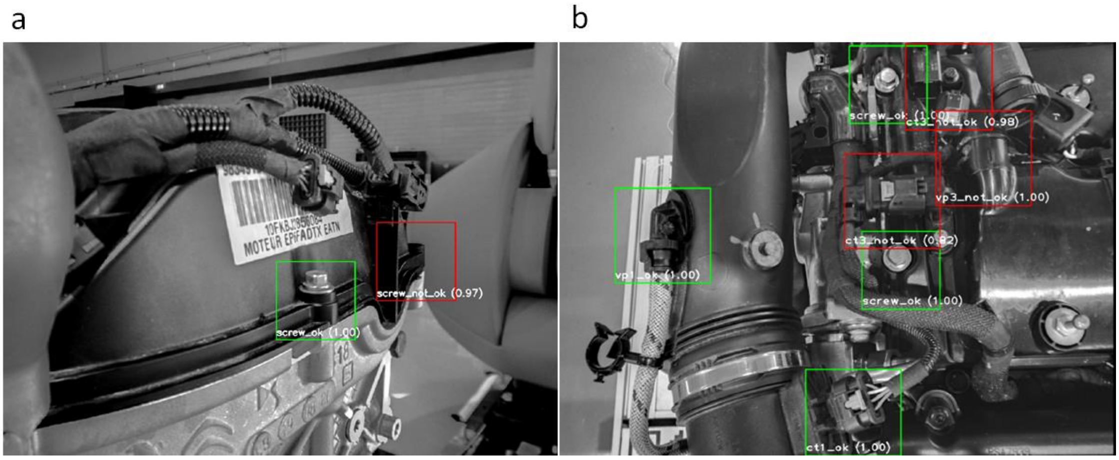


Figure 13: Quality check result: a) Top motor view; b) Right motor view

3.3.3. Spatial Object Detection Module

As specified in D2.4, a pivotal element of robotic perception, critical for the ODIN Automotive Pilot line, involves accurately determining the positions of screw holes in components. In the context of the Automotive pilot scenario, where the assembly process of an automobile engine is investigated, the motor and gearbox undergo precise alignment. For this alignment procedure, the object detection and position identification module for alignment holes and motor's central axle has been employed. This vision system involves a Convolutional Neural Network (CNN) approach, leveraging state-of-the-art deep learning techniques. The detection process calculates the coordinates of recognized objects, providing the required alignment positions for robot's motion adjustments during the assembly process.

This module's testing has been conducted in the LMS small-scale pilot. The sensory input for image and depth data are derived from the RC_Visard 160 camera of the COMAU AURA robot. The specific installation point of the camera on the robot's end effector guarantees that both the connective pins and the central axle fall within its field of view of the camera. The outcomes of the module's testing are presented below.

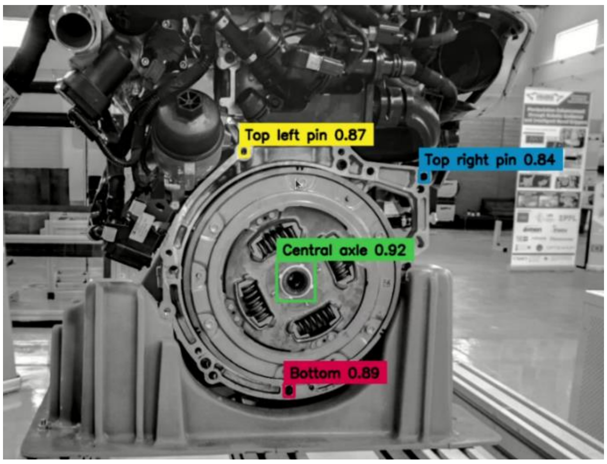


Figure 14: Detection of motor screws and central axle

3.4. Smart human side interfaces

Based also on deliverables D2.3 and D2.4, the AR application ODIN has been developed by LMS supporting human operators during the assembly tasks' execution. The final version of this application has been validated inside the two small scale pilots of LMS. As described in D2.5, several features for the application were identified as necessary for integration based on feedback from the end users.

Table 2: ODIN AR features and implemented pilots

Feature	Title	Automotive Pilot	White Goods Pilot
AR_F1	Visualization of Human assigned tasks through AR	X	X
AR_F2	Task Completed virtual button	X	X
AR_F3	Robot trajectory visualization inside the virtual world	X	X
AR_F4	Easy robot programming using interactive virtual tool	X	X
AR_F5	Security alarm visualization	X	X
AR_F6	Error handling in case of detection process failure	X	X
AR_F7	Resilience – execution error recovery	X	X
AR_F8	Robot's safety zones visualization through AR Glasses	X	
AR_F9	Quality inspection results visualization, digitally mark for validation and instructions provision for corrections	X	
AR_F10	Alarm indicating that the robot is working in collaborative area		X
AR_F11	Interaction with mechatronic devices		X
AR_F12	Production schedule visualization	X	X

The final version of the AR application includes the above-mentioned features which have been completed and are integrated in the small scale pilots of ODIN.

- AR_F1: Visualization of Human assigned tasks through AR and AR_F2: Task Completed virtual button

As already described in D2.5 the module is implemented and tested as part of the LMS small-scale pilots (Figure 15). The testing was conducted with the operator receiving alerts regarding the assigned to him tasks and their successful execution.

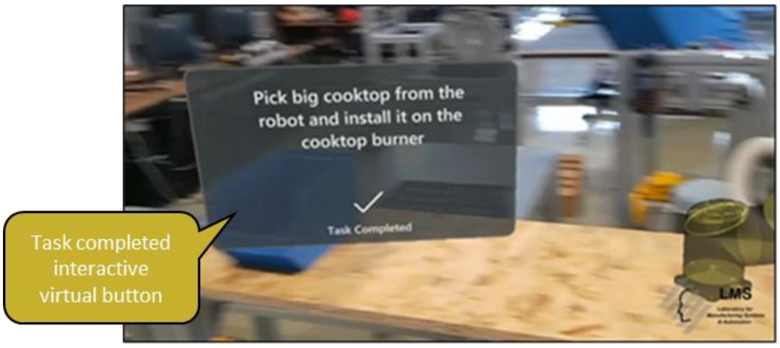


Figure 15: Integration of AR_F1 and AR_F2 under the small-scale pilots of LMS

- AR_F3: Robot trajectory visualization inside the virtual world

Following the implementation of D2.5 the feature was tested also under the small-scale pilots of LMS. Modifications were made to visualize the trajectory of the robot and the end effector colourful line inside operators' field-of-view in a more clearly and distinctly way.

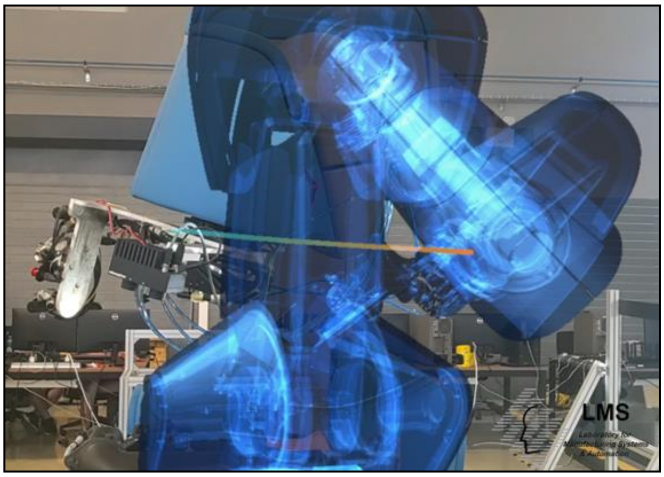


Figure 16: Integration of AR_F3 under the small-scale pilots of LMS

- AR_F4: Easy robot programming using interactive virtual tool

This feature of the AR application enables human operators' interaction with the robots of the LMS small-scale pilots to define new robot poses. In its final version this feature supports connection with different robot end effectors.

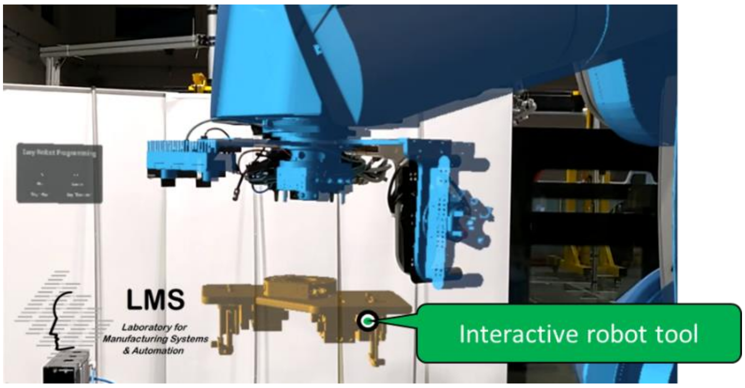


Figure 17: Integration of AR_F4 under the small-scale pilots of LMS

- AR_F5: Security alarm visualization

Through the AR application and information derived from OpenFlow the operators of the production line are aware in case of cyber security threats detected inside the network of ODIN production lines. This feature of the AR application has been validated through the two small scale pilots of LMS.

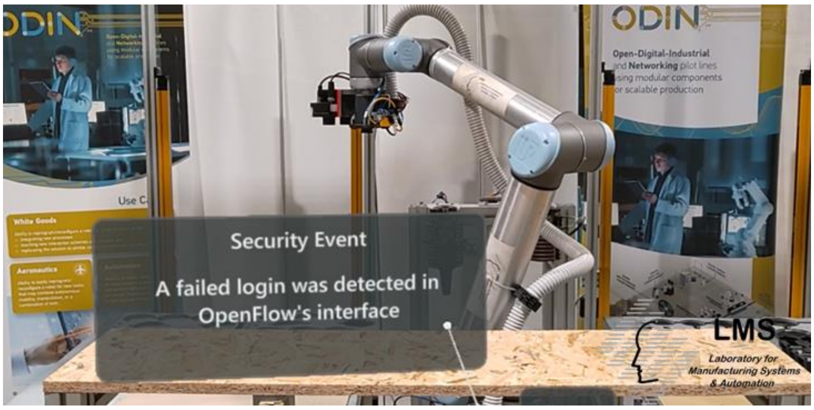


Figure 18: Integration of AR_F5 under the small-scale pilots of LMS

- AR_F6: Error handling in case of detection process failure

This feature has been detailly presented in deliverable D2.5. It has been tested in case of failed detection of big cooktops in the White Goods pre-industrial demonstrator. The camera failed to detect the cooktops, and a corresponding alarm was presented to the operator along with a new task to correct the position of the robot.

- AR_F7: Resilience – execution error recovery

As presented in deliverable D2.5, the AR application enables the recovery of the system in case of different unexpected failures during the assembly operation. Through a set of recovery functions, operators are able to interact with the OpenFlow and recover of the system on-the-fly through the AR applications' interactive buttons.

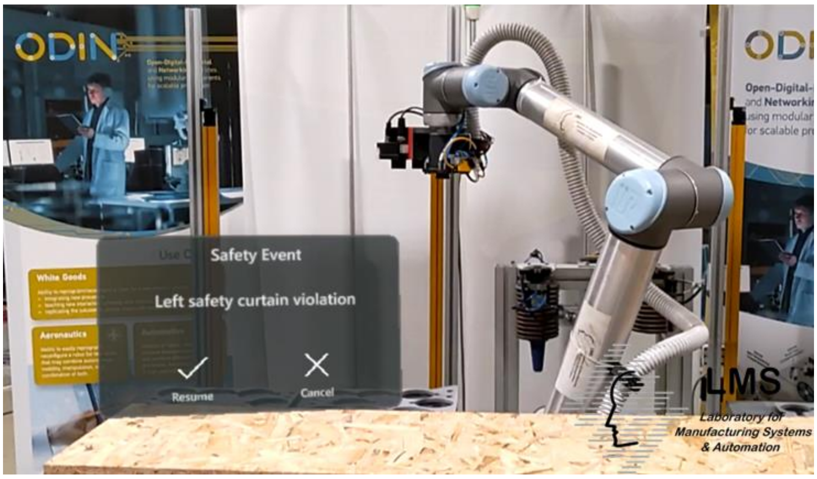


Figure 19: Integration of AR_F7 under the small-scale pilots of LMS

- AR_F8: Robot's safety zones visualization through AR Glasses

Using the real-time sensor data from the COMAU mobile robot, operators equipped with an AR headset are able to check the safety zones around the mobile unit through the virtual world of the AR application. The final version of the AR application has been validated through both small-scale pilots of LMS in order to test application's connection with COMAU and UR robots.

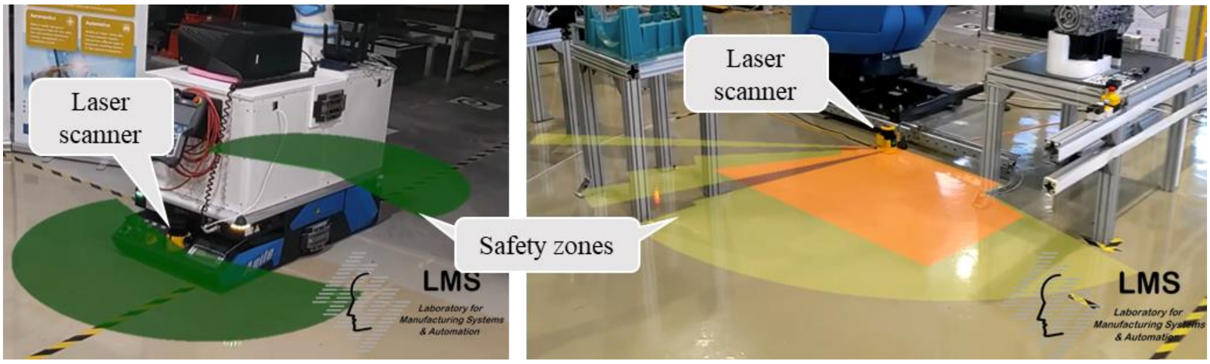


Figure 20: Integration of AR_F8 under the small-scale pilots of LMS

- AR_F9: Quality inspection results visualization, digitally mark for validation and instructions provision for correction

This module as described in D2.5 has been finalized and its functionality has been tested at LMS small-scale pilot. This feature provides 3D space indicators to the operator alongside with the part and corrective action that needs to be performed (Figure 21).

Figure 21: Integration of AR_F9 under the small-scale pilots of LMS

- AR_F10: Alarm indicating that the robot is working in collaborative area

The AR application supports alerts to the operator every time the robot enters one of these areas. The feature has been tested as part of the LMS small-scale pilot for white goods with an alarm indicating the robot was entering the pre-defined area (Figure 22).

Figure 22: Integration of AR_F10 under the small-scale pilots of LMS

- AR_F11: Interaction with mechatronic devices

As documented in deliverable D2.5, this feature of the AR application is utilized for the direct interaction of human operators with mechatronic devices of the LMS White Goods small scale pilot and more specifically with the magnetic gripper of the UR10 collaborative robot. Upon human request, the UR10 robot is able to approach a pre-defined position and wait for human hand to be detected in order to disable the magnetic gripper and release the grasped object directly on operator's hand.

Figure 23: Integration of AR_F11 under the small-scale pilots of LMS

- AR_F12: Production schedule visualization

Based also on the description provided in D2.5, through the AR application of ODIN, human operators are aware on-the-fly regarding the assembly operations to be performed but also on how to perform them in order to ensure the high quality of the products. This feature has been tested inside the white goods small scale pilot of LMS and the corresponding data of the assembly operation included in the data base of OpenFlow.

3.5. Adaption of safety aspects for validation

During the 5th GA in June of 2023 PILZ, performed a Preliminary Safety Verification of the Automotive and White Goods small scall pilot at LMS premises. The preliminary verification had the objective of conducting a thorough assessment of the safety aspects associated with the equipment, hazards, and overall safety concepts. The preliminary verifications were based on the safety concepts described in section 4.2 - Safety Concepts of D5.1.

Due to the nature of tsmall-scaleale pilots, some of the requirements of the safety concepts that have been proposed in D5.1 needed to be adapted in accordance with the layouts of the small scale pilots. The objective of this adaptation is to allow a detailed understanding of the proposed safety solutions for the small-scale pilots that were built at LMS premises. These solutions are presented to ensure the machine complies with the mechanical, electrical, pneumatic and control requirements in this first phase of the project.

After that preliminary verification PILZ created a report with a checklist of all the safety requirements missing to be able to validate the small scales pilots of Automotive and White Goods . With the support of PILZ, LMS has implemented all the safety requirements needed to reduce all risks to acceptable levels for the Automotive and White Goods small scall pilot at LMS premises.

Figure 24: Safety Scanners installed at LMS Automotive Small-Scale Pilot

Figure 25: Light Barriers installed at LMS Automotive Small-Scale Pilot

See Annex 1 for the Preliminary Safety Verification report of LMS Automotive small-scale pilot and Annex 2 for the Preliminary Safety Verification report of the LMS White Goods small scale pilot. These reports have a detailed list a of all the safety requirements that have been implemented in the small scall pilot at LMS premises. PILZ has validated that the pilots meet all the safety aspects associated with the equipment, hazards, and overall safety concepts.

For more information on the requirements for each safety function check the section 4.2 - Safety Concepts of the D5.1.

4. TECNALIA SMALL SCALE PILOTS

In this section the Small-Scale Pilots developed by TECNALIA are presented. The status of Small-Scale Pilots at M36 has allowed validating the key enabling technologies in a different set-ups that are feasible to transfer into Large Scale Pilots, both at TECNALIA’s facilities or at end-users' premises.

4.1. Autonomous mobile manipulators

The mobile manipulator that TECNALIA is using at ODIN project is shared by the Aeronautics and Automotive pilots. At previous stages of the project, some of the technology was tested and validated at different robots, currently on M36 all the key enabling technology has been integrated into the same robotic platform.

The robotic platform not only has been enhanced integrating 3D navigation technology; also, additional safety equipment has been added to preparing to comply with the security concept presented in ODIN. The details of the safety concept will be presented at Section 4.5.

Aeronautics

At this phase, the cart which contains the Fan Cowl has been modified, elevating the part above 200mm for clearing the view of the laser scanners. The screws used to elevate the part are small enough to filter them properly and avoid the self-collision detection. Despite the fact the docking mechanism that will allow attaching the Fan Cowl cart to the autonomous mobile manipulators is not available yet, a temporal mechanical fix has allowed performing successful tests of Fan Cowl transportations along the TECNALIA’s workshop (Figure 26). For the Small-Scale pilot, the footprint of the robot has been adapted with the surface occupied by the Fan Cowl. As a result, the assembly can navigate autonomously without colliding with the environment. For the Small Scale pilot, the footprint switching is performed manually, i.e., launching the set-up with the corresponding shape configuration parameters (Figure 27).

Figure 26: Fan Cowl transportation and handling prototype

The Transporting operation (BUC-O2 Transportation and Handling) has been validated in TECNALIA small scale pilot for aeronautics. At M36 the feasibility of transporting big parts as Fan Cowls has been demonstrated.

Figure 27: 3D Octomap for environment representation. Robot + Fan Cowl cart footprint (in green)

Automotive

Regarding the automotive use case the Small-Scale pilot developed at TECNALIA premises at M36 allows validating the capability of the autonomous mobile manipulators of following a target at 6 m/min, which is the commanded speed of the conveyor at the Large Scale pilot.

Since at TECNALIA premises there is not a long enough conveyor belt (Figure 28) for validating the stability of the proposed target following technology, an AGV has been used for assuring the feasibility of the concept. Thanks to the versatility of the AGV, the target following strategy has been possible to test at different speeds, and even with changes in the direction (Figure 29). The results of the test show how the autonomous mobile manipulators can follow targets at a 9 m/min with a reasonable deviation. Since the required speed is 6 m/min, the feasibility can be claimed.

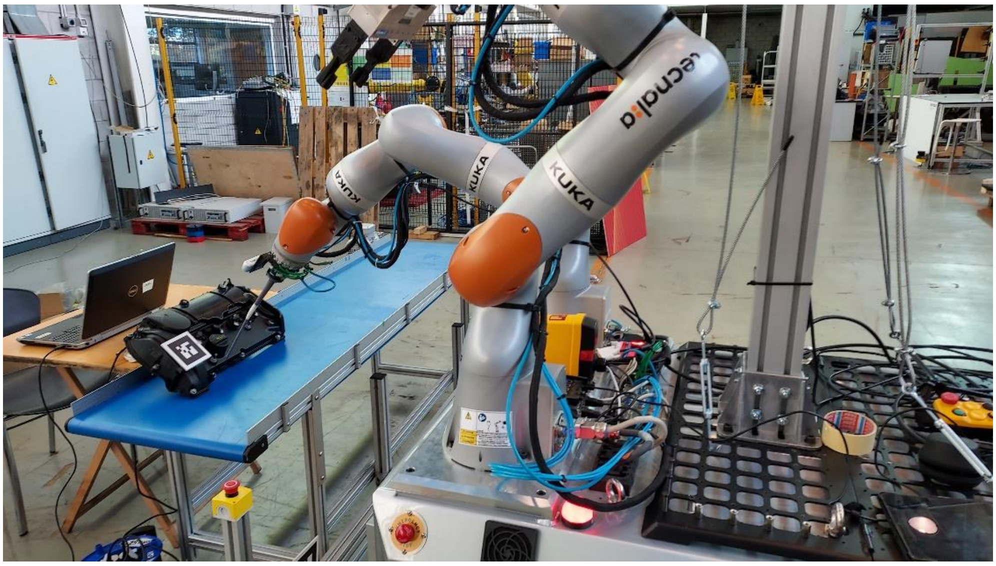


Figure 28: The small conveyor belt available at TECNALIA premises

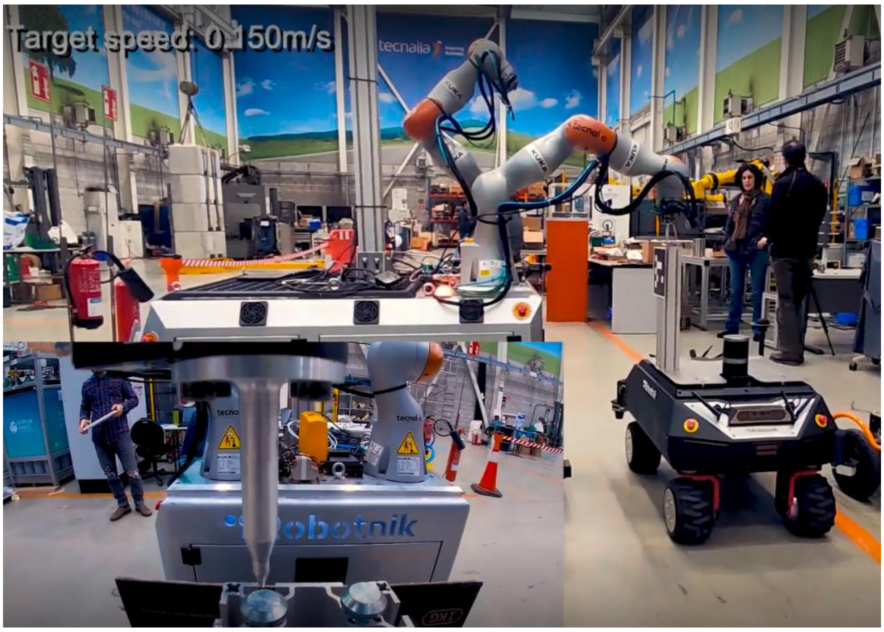


Figure 29: Target following tests at 9m/min

4.2. Reconfigurable robot tooling

At previous states of the project, due to robotic platform availability limitations, key-enabling technologies were tested in various robotic devices. At M36, all the Small-Scale pilots developed at TECNALIA premises, are using the same robotic platform (with the exception of the quality inspection operations that will be introduced in the 4.3 Section). On the one hand, this is thanks to the hardware agnostic software development that always has been in mind, and on the other hand due to the reconfigurable robot tooling that has been implemented.

Figure 30 presents how different tools can be equipped by the same robot thanks to Schunk automatic tool exchangers. Additionally, the figure shows how the tools can be stored in a tool warehouse equipped by an AR marker in order to allow the detection through computer vision techniques.

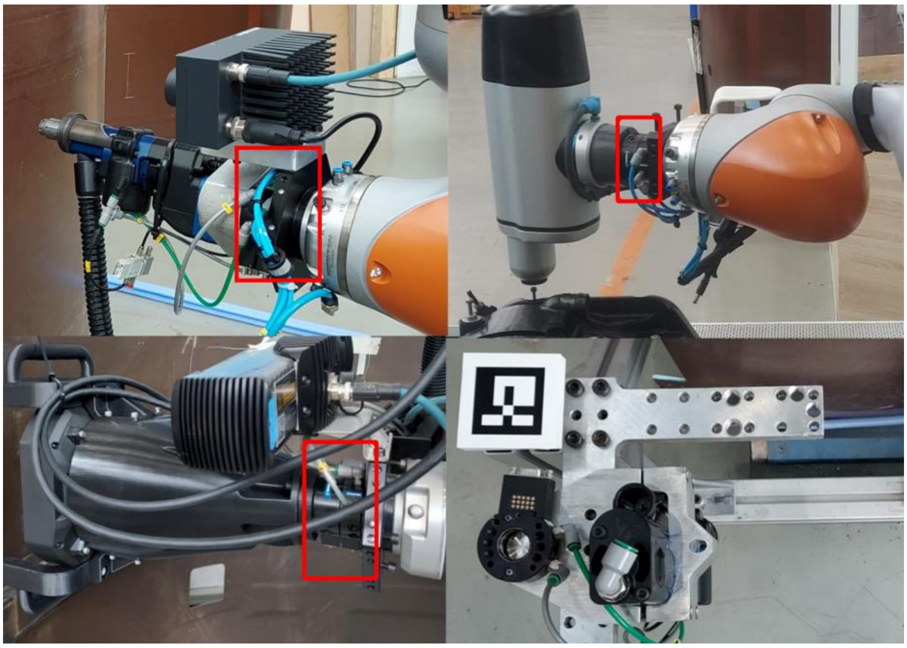


Figure 30: Reconfigurable robot tooling devices deployed at TECNALIA Small Scale pilots

4.3. Robotic perception for the environment, process and human

In ODIN different perception key enabling technologies have been developed. The Small-Scale pilots at M36 are a significant representation towards the Large Scale pilots in the end users. In the following subsections, divided per end user, the details of the TECNALIA Small Scale pilots can be found.

4.3.1. Aeronautics

BUC-01: Template/tooling based drilling

Template based drilling operation is composed of several steps. The first step is to approach the robot to tool warehouse. Next, the drilling tool is equipped. Then, the drilling machine is moved towards the drilling template while avoiding collisions with the environment. Once the drilling template is detected, the machine is inserted into the template. Finally, the drilling process is triggered.

The steps related to robot movement are programmed using the teach-by-demonstration approach. The taught trajectories are adapted with the result pose of the template, allowing more flexibility and avoiding expensive docking and calibration methods. At M36, the template detection has evolved from using AR markers (Figure 31) to integrating ROBOCEPTION CADMatching detection features (Figure 32).

Figure 31: AR marker template detection

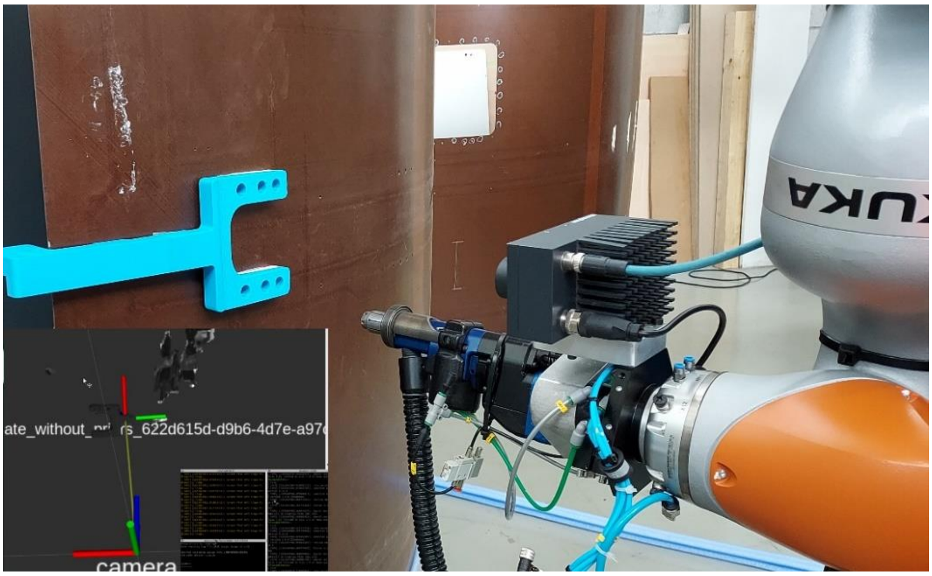


Figure 32: Template detection through ROBOCEPTION modules

BUC-03: Quality inspection

At M36 the TECNALIA Small Scale pilot for quality inspection of aeronautics parts has enabled the creation of a setup to test various approaches using 3D scanning and reconstruction techniques. The objective is to evaluate the presence/absence of parts, position and orientation issues, correctness of fittings, as well as gaps and step measurements.

At this version of the Small Scale pilots the Photoneo sensor [13] has been used for scanning an actual part of the Fan Cowl (Figure 33).

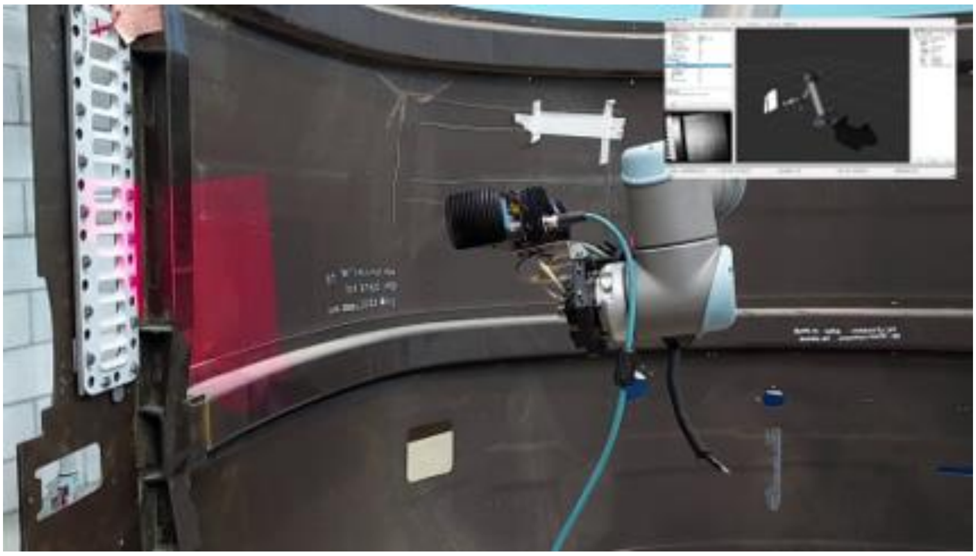


Figure 33: Part scanning for performing a 3D reconstruction

The obtained 3D model is used as reference (grown truth model) for future scans. If successive scans reconstruct a significantly different model, it is detected by the vision algorithm and returns an alert. In the Figure 34 a result of a reconstruction is shown, additionally, a segmentation of the image is shown, highlighting the target part.

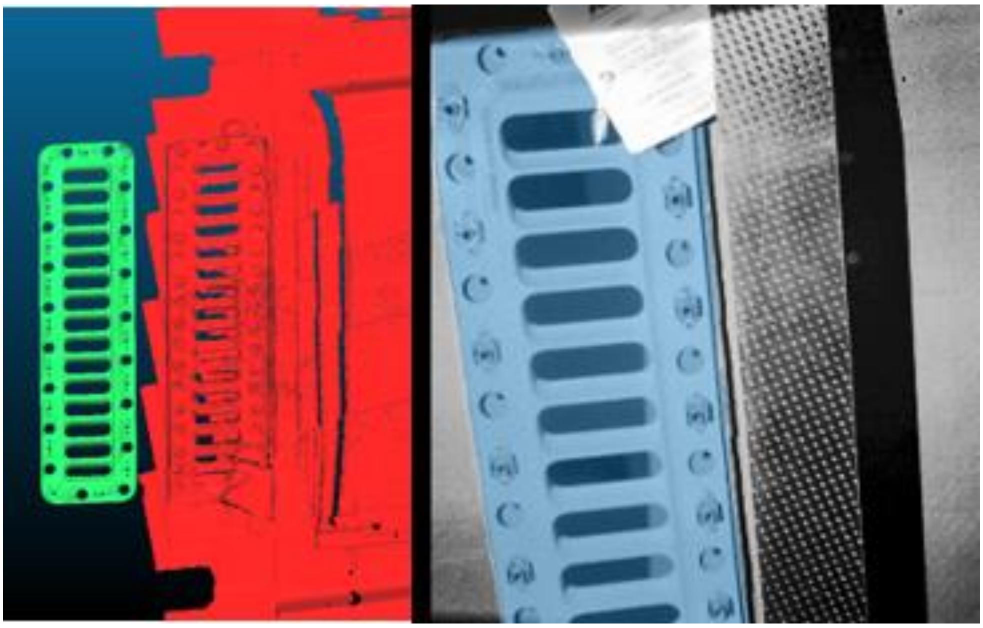


Figure 34: 3D reconstruction and segmentation

Besides 3D based quality inspection approaches, the TECNALIA Small Scale pilot contains the integration tests of the Keyence sensor that AEROTECNIC is interested to evaluate for some of the inspections. This sensor has been equipped together with the Photoneo, but as can be seen in the Figure 35, they cannot work at the same time. That is why it has been mounted using a Schunk tool exchanger for a quick mount/dismounting. The Keyence sensor has proven to be interesting for the measurement of gaps and steps (Figure 36)

Figure 35: Integration tests with Keyence sensor

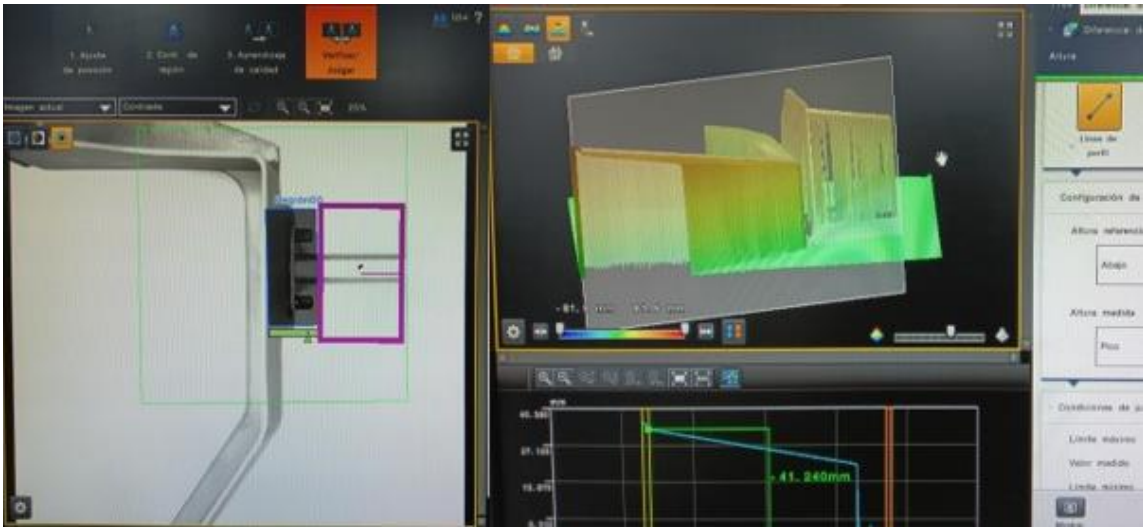


Figure 36: Keyence measurements tests results

4.3.2. Automotive

The perception, specifically visual servoing, is one of biggest challenges of the BUC-02: Screwing while moving. Tracking the motor/gearbox along the conveyor requires the development of advanced control techniques for combining the motion of the robot platform + robot manipulator which equip the screwdriver.

At M36 the Small Scale pilot developed at TECNALIA improves and generalizes the visual servoing module, making it more re-usable, robust and reliable. In previous developments, on the one hand, the platform tracks an AR marker for following the conveyor, and on the other hand, the robot manipulator uses another camera for tracking the motor itself. At M36, both control loops have been combined successfully, requiring only one camera for motor/gearbox tracking. Thanks to this evolution the dynamics and reaction of the system have been considerably improved.

As can be seen in Figure 37 the software architecture has been updated allowing an easier integration of different hardware. With the current proposal, not only can screwing operations be automated, but it also opens up a range of possibilities for automating any operation in motion.

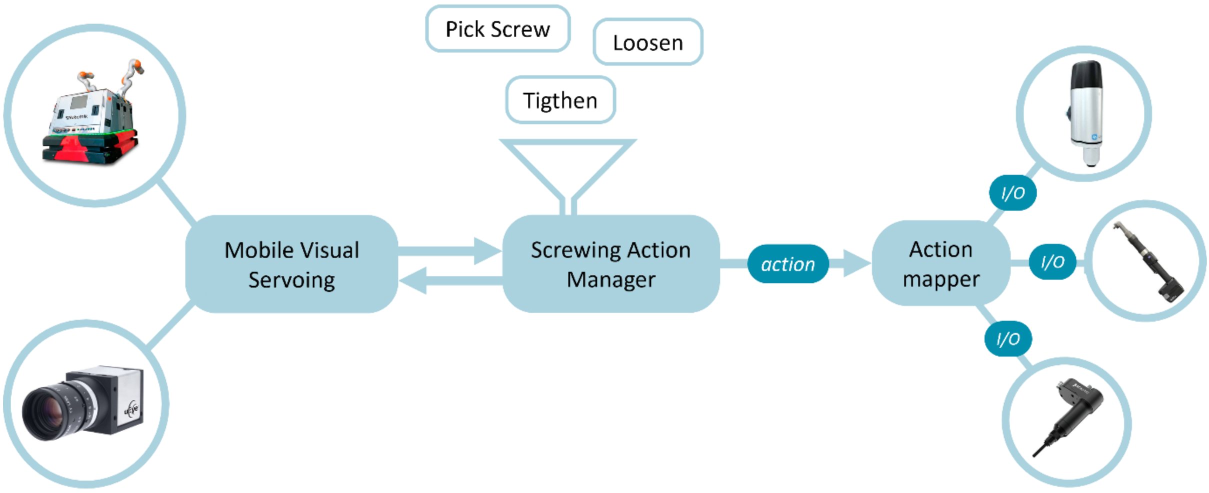


Figure 37: Improved software architecture for an easier hardware integration

The TECNALIA Small-Scale pilot has enabled the validation of visual servoing technology in a more realistic scenario. As mentioned above, since the available conveyor is too small, an AGV has been used for testing the motor tracking algorithms and confirming that the objective speed (6 m/min) can be achieved). At Figure 38 how the robotic platform is tracking the motor while performing an operation is shown.

Figure 38: Motor tracking at 6 m/min

At this stage of the project, the TECNALIA Small Scale pilot also contains a mock up of the motor for performing screwing tests (Figure 39).

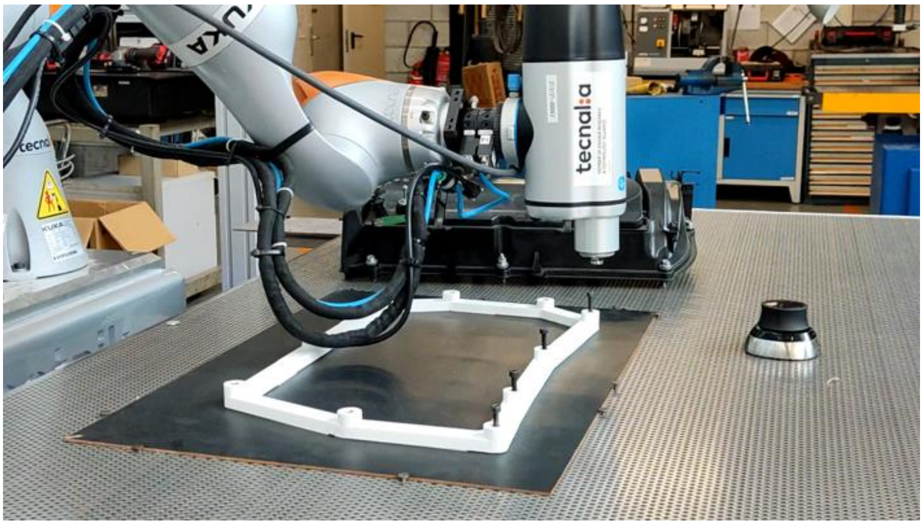


Figure 39: Screwing tests in a mock-up

4.4. User friendly robot programming interfaces

Regarding the interfaces, a lot of the efforts have been dedicated to bug fixing and improvements in user experience. One of the most remarkable points is the integration of the OISP (Onsite Interactive Skill Programming) with Blocky based GUI for Skill sequencing and parametrizing (Figure 40).

Figure 40: Improvements in the GUIs for user friendly robot programming

The improvements made are described in D2.5 and their integration with the pilots are presented in D5.4.

4.5. Adaption of safety aspects for validation

Due the nature of the small-scale pilots, some of the requirements of the safety concepts that have been proposed in D5.1 needed to be adapted in accordance with the layouts of the small-scale pilots. The objective of this adaptation is to allow a detailed understanding of the proposed safety solutions for the small-scale pilots that were built at TECNALIA premises. These solutions are presented to ensure the machine complies with the mechanical, electrical, pneumatic and control requirements in this first phase of the project.

At this stage of the project, in the small-scale pilots at TECNALIA premises, all the necessary hardware, the feasibility of installation in the available space and to retrieve the information regarding the necessary software changes in the existing safety PLC has been identified and are currently in process of being implemented.

On the one hand, the place for installing the required SICK IO modules and PILZ safety PLC has been identified and measured, concluding its suitability. On the other hand, the KUKA connector X11 has been identified where the emergency outputs must be wired to the SICK IO modules. In addition, it has been verified that the cables can be routed along the same path as the existing cables (Figure 42).

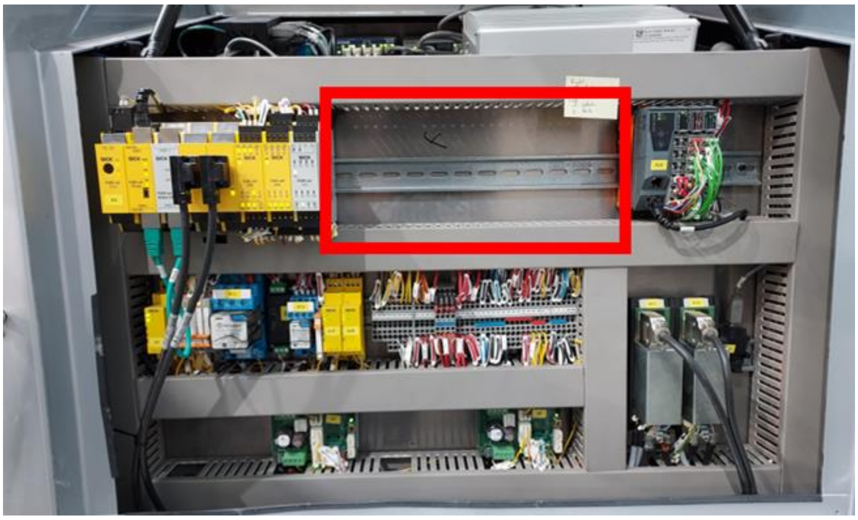


Figure 41: **Place for SICK IO modules and PILZ safety PLC**

Figure 42: KUKA IIWA X11 connector where safety signals must be wired

More information on the safety requirements for the pilots are presented in sections 4.2 and 5.2 - Safety Concepts of the already submitted deliverable D5.1.

5. AIC SMALL SCALE PILOT

The small-scale pilot of AIC is installed at the ASF-Automotive Smart Factory. As presented also in D2.3, the ASF is an AIC Competence Center specialized in advanced manufacturing, providing integral services for the implementation of Industry 4.0.

In the ASF, the mobile robot of AIC is utilized for the inspection process of engine components on a conveyor belt:

- Motor’s detection by the conveyor belt triggering conveyor’s enabling.
- Motor’s transportation along the conveyor belt and inspection of assembled parts using a camera installed on the robot.
- Visualization of inspection results in real time on a monitor in the ASF plant.

This small-scale pilot provides knowledge and integrations of a flexible inspection process, compatible with an advanced manufacturing process for a large-scale pilot. All this started from AIC's facilities and extrapolated to end users.

The ability to carry out an inspection of an engine in motion, simulating the possibilities of making an inspection process flexible and not having to be static in a large plant has been validated in this small-scale pilot. An important hardware component of this small-scale pilot is a conveyor belt for motor transportation and 180 degrees rotation towards the completion of the inspection tasks.

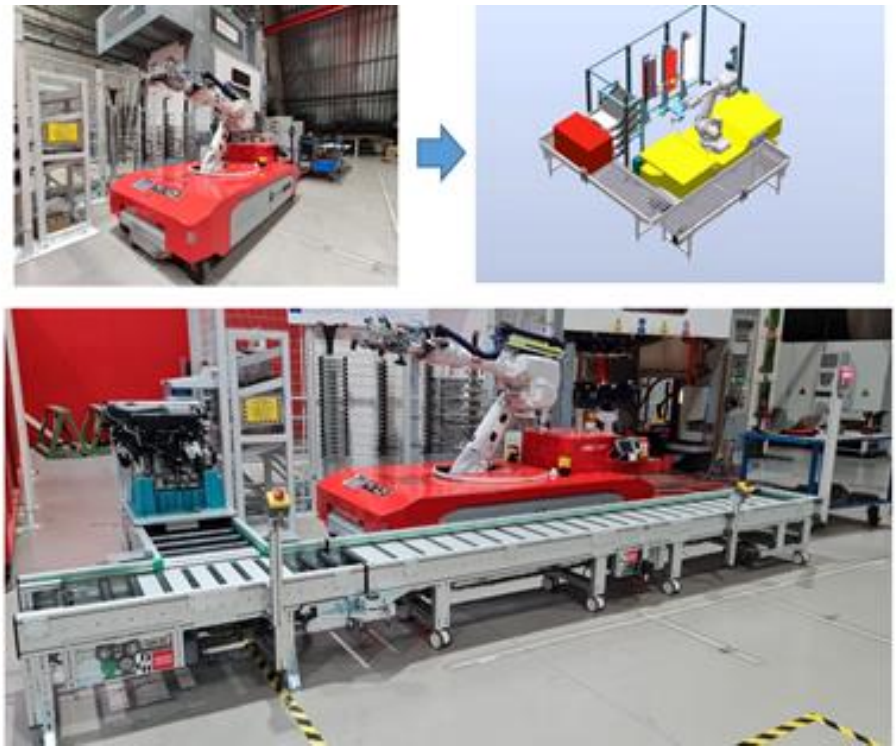


Figure 43: Quality Control Cell and AIC mobile robot integration

5.1. Autonomous mobile robot

The robotic platform of AIC is utilized for the testing and validation of ODIN solution for assembled parts’ inspection. This mobile robot consists of an AGV and an industrial robot manipulator for the execution of handling and quality inspection tasks. These tasks require the autonomous navigation of the platform at ASF layout.

For the realization of ODIN concept, different sensors, devices and robot grippers have been installed on the robot arm as presented in the following figure.

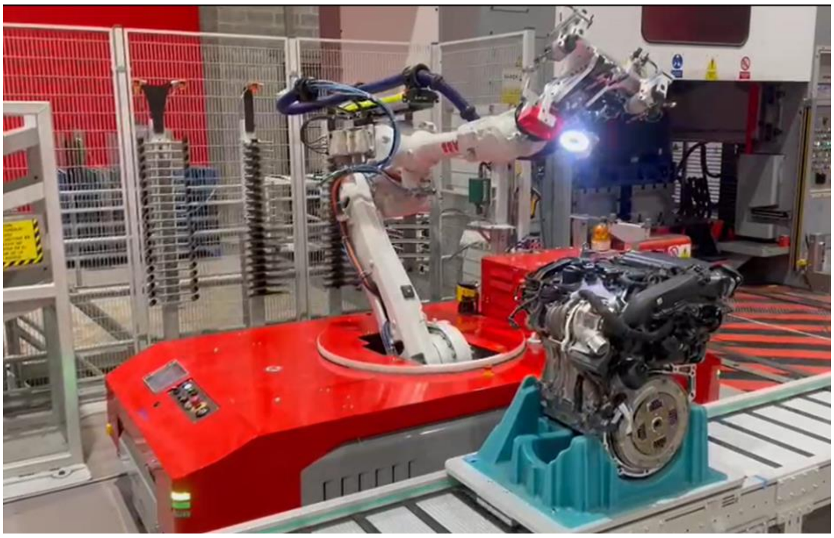


Figure 44: Quality inspection operation at ASF

The validation of ODIN solution in an advanced manufacturing area, is based a reconfigurable small working area demonstrating the execution of different type of operations under the same working area without time lost due to reconfiguration activities. The navigation abilities of the AGV and the reconfigurable shape of the conveyor increased the overall flexibility of the solution.

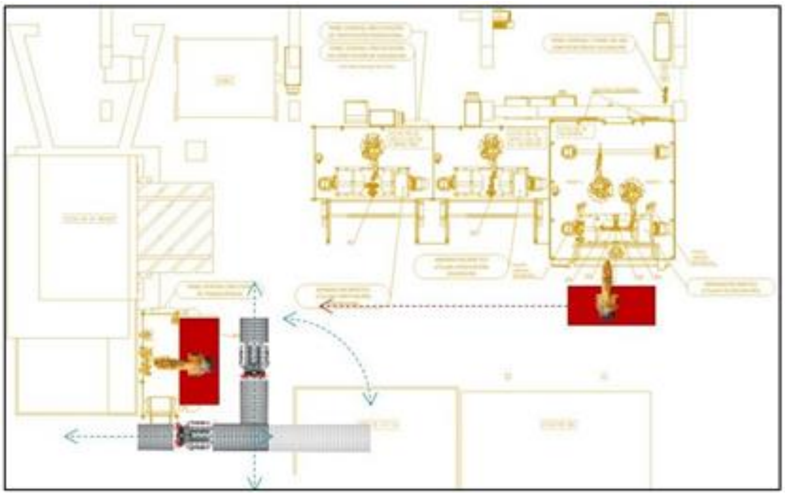


Figure 45: ASF layout reconfigurability

5.2. Robotic perception for the environment, process and human

The final version of the Artificial Intelligence based quality inspection solution of DGH is presented in this section of the document. This inspection operation is based on a 2D Genie Nano C2020 camera [14] from Infaimon. This module’s software has been developed using Halcon DL and Open AI Algorithms. As presented also in D2.3, this software consists of two different tools, the Learning tool and the Production tool. The final version of this software solution is detailly presented under D2.4.

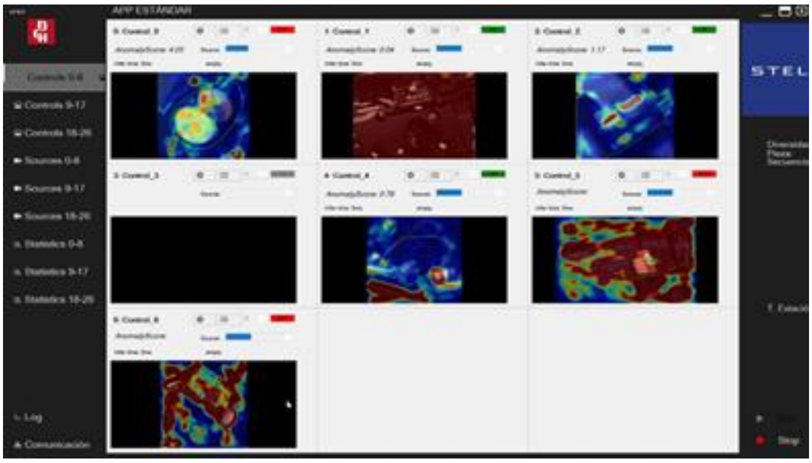


Figure 46: DGH Deep Learning HMI Tool

The camera sensor is installed on the robotic manipulator towards the increasement overall solution flexibility. The mobile robot is able to navigate inside the layout and perform the quality inspection operation on the fly. Focusing on end-of-line quality inspections, we are looking for maximum flexibility in order to waste as little time as possible and achieve the greatest possible safety for the operators. In the final version of the AIC small-scale pilot, it is demonstrated that neither the quality inspection sensors nor the inspected product are needed to be in a fixed location. In this way it is validated that in case of ASF layout's re-organization, the minimum amount of resources' effort and execution time is required.

At the same time, given the required flexibility from the end users' point of view, the quality inspection solution tested inside the small-scale pilot at AIC with inexpensive technology and a software module developed by DGH that is very easy to be learn. Thanks to the user-friendly interface of the software, no support from a third party is required for training purposes. This means that not much time is required for software module's training to the operators.

5.3. Adaption of safety aspects for validation

With the support of AIC and DGH, PILZ conducted a Preliminary Safety Verification of the AIC small scall pilot at AIC premises. The preliminary verification had the objective of conducting a thorough assessment of the safety aspects associated with the equipment, hazards, and overall safety concepts. The preliminary verification was based on the AIC safety concept described in section 4.2 - Safety Concepts of D5.1.

The Preliminary Safety Verification report with all the hazards identified and all the ongoing solutions that will be implemented by AIC is presented in Annex 3.

Figure 47: Emergency stop buttons of AIC small Scale Pilot

6. KTH SMALL SCALE PILOT

The developed human motion recognition method is deployed in the KTH small-scale pilot for extensive experiments. The final prototype involves a Kinect V2 camera for capturing the RGB-D video stream of the scene and the skeleton sequence of the human operator, a human operator, two ABB robot arms (IRB 120 [15] and IRB 1600 [16]), a shared workspace with assembly parts and tools, a workstation computer for processing the input data and recognizing the ongoing actions of human operator. The perception results will be sent to the robot controller for robot procedure generation.

6.1. Robotic perception for the human

The overall configuration of the pilot is shown below in Figure 48.

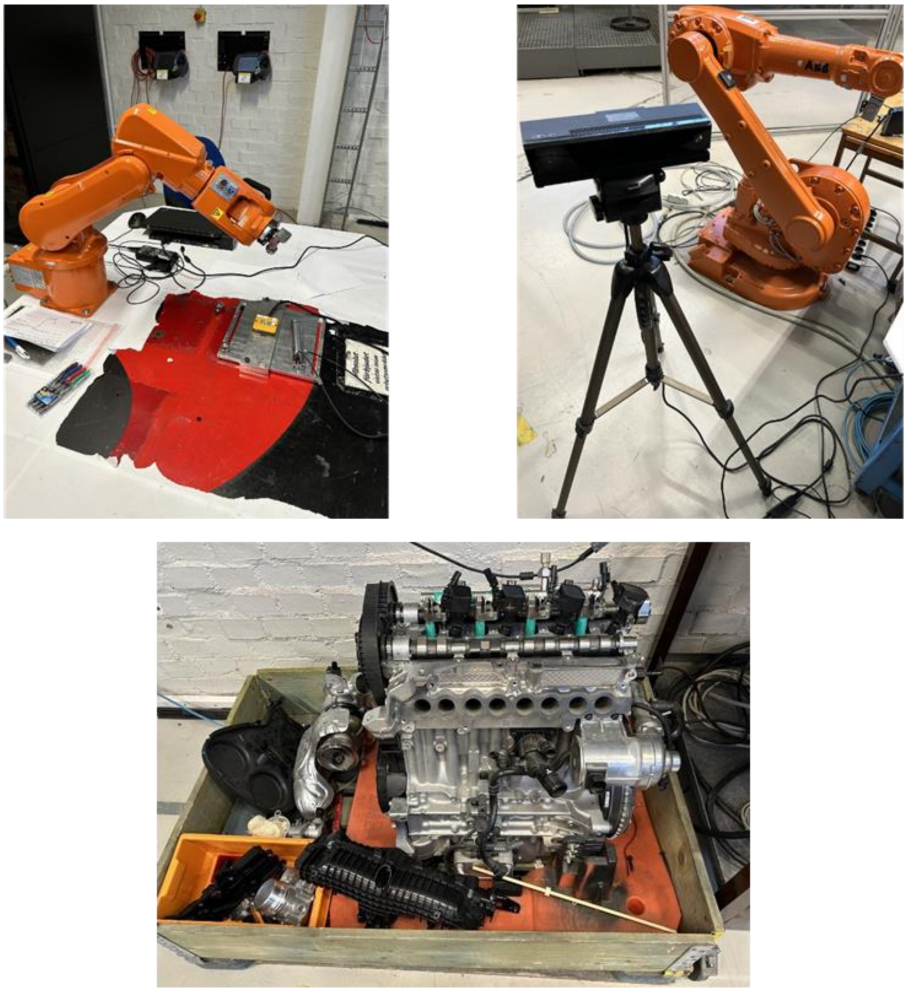


Figure 48: The experiment configuration of KTH small-scale pilot

Two sets of actions are designed. The first set corresponds to an assembly task of engine top part. Three actions are involved: plug in the tube, tighten the screw, put on the cover (Figure 49). Full human body skeleton is detected (25 joints). Figure 50 shows the accuracy curves of training and validation during the model finetuning. The pre-trained model on NTU RGB+D dataset is used for finetuning on the collected data in the pilot.

(a) Plug in the tube

(b) Tighten the screw

(c) Put on the cover

Figure 49: The first set of actions in the experiments

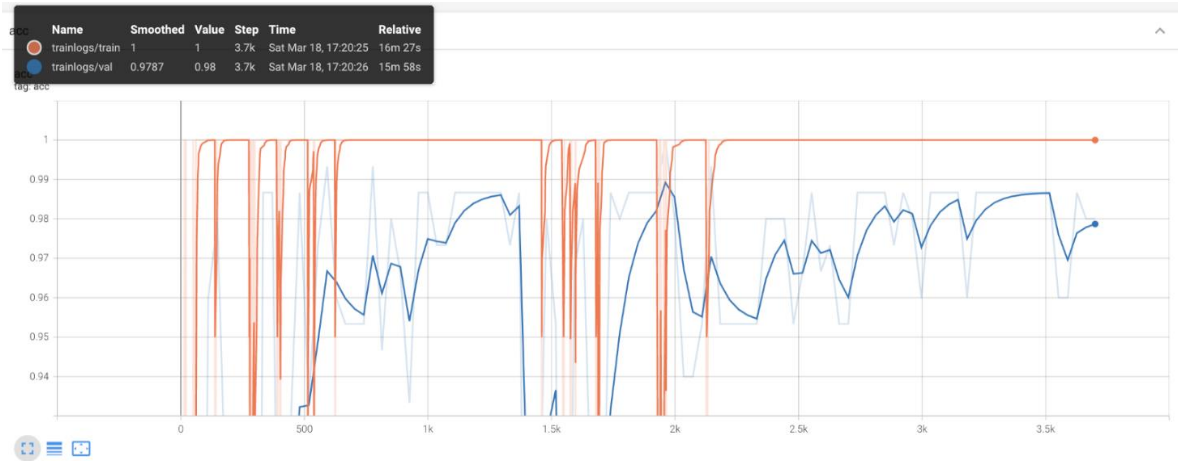
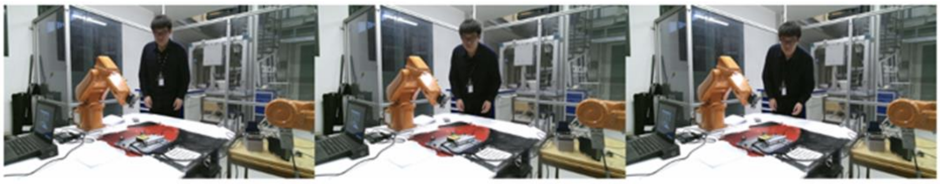


Figure 50: The training and validation accuracy curves for the first action set

The second set of actions corresponds to a simple collaboration task between human and robot. Four actions are defined: wait for robot operations, pick-and-place, tighten the screw, wave the hands (Figure 51). Only the upper part of human body skeleton with 17 joints is tracked due to the constant occlusion of the workbench. Due to the fine-grained actions and less discrepancies between different actions, the accuracy drops a little (Figure 52). Further improvements are being conducted to make the developed method generalize to various conditions.



(a) Wait for robot operations

(b) Pick and place

(c) Tighten the screw

(d) Wave the hands

Figure 51: The second set of actions in the experiments

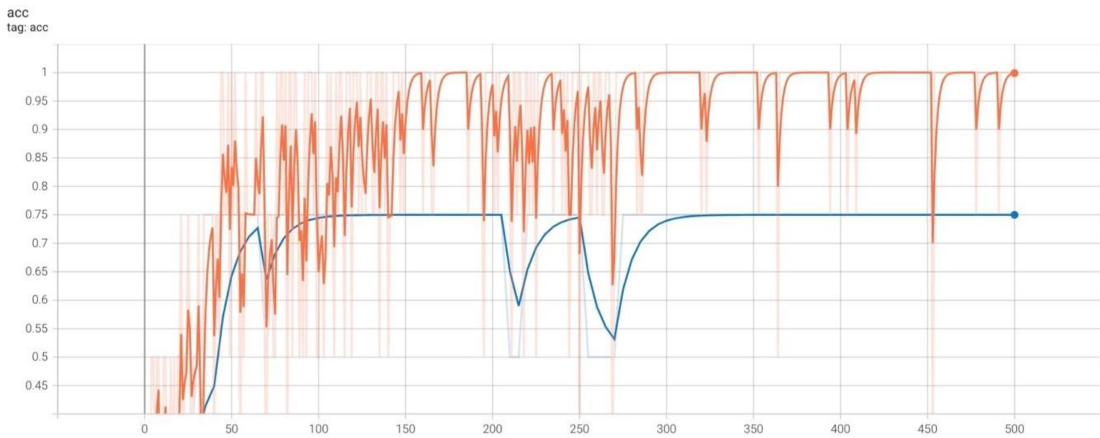


Figure 52: The training and validation accuracy curves for the second action set

The developed method is adapted for the online real-time application in the KTH small-scale pilot. A multi-threaded implementation is achieved with the socket communication between the Kinect V2 sensor, the computer, the ROS platform and the ABB robot arm (Figure 53). It is observed that the recognition results are accurate and stable during the application, indicating the developed method is ready for the deployment in other pilot cases.

Figure 53: Some examples of online real-time application in the KTH small-scale pilot

7. TAU SMALL SCALE PILOT

Under the White Goods pilot, the human operator needs an easy and user-friendly way to work with a robot. The concrete application consists of a robot picking up transformers and placing them on a surface so the operator can continue to perform assembly tasks on these transformers in ergonomic way. In this environment, the robot and a human operator share a common workspace, so the application's focus is about safety with an efficient workflow.

7.1. Smart human side interfaces

As presented in deliverables D2.3 and D2.5, the environment must be correctly calibrated to be able to detect the operator as well as to project a smart interface. In the small scale pilot of TAU, a single table to display a smart interface along with static borders where the robot would place the transformers is utilized (Figure 54).

7.1.1. TAU Robolab Environment

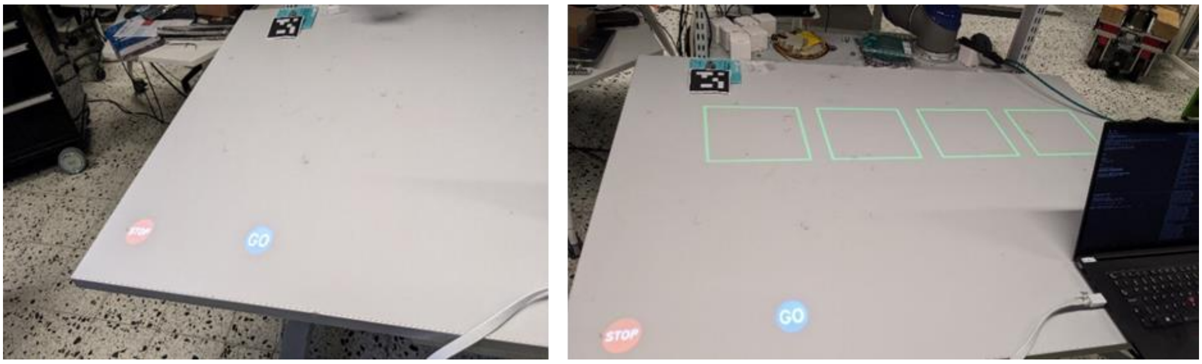


Figure 54: (Left) Smart interface to start the robot (GO button) or stop it (STOP button). (Right) Static borders where the robot will place the transformers. Only one transformer per slot is allowed

Before placing a transformer inside a slot of the assembly table, the robot books a static border to notify the operator. Then, the booked border change its color. When a slot is booked, the operator should not cross its border anymore. A depth camera monitors the operator to verify that there is no violation of the border. In addition, a hand detector complements the depth camera to ensure that the border crossing is not caused by the robot. If the size of the robot is consequent, the system also books adjacent borders (Figure 55).

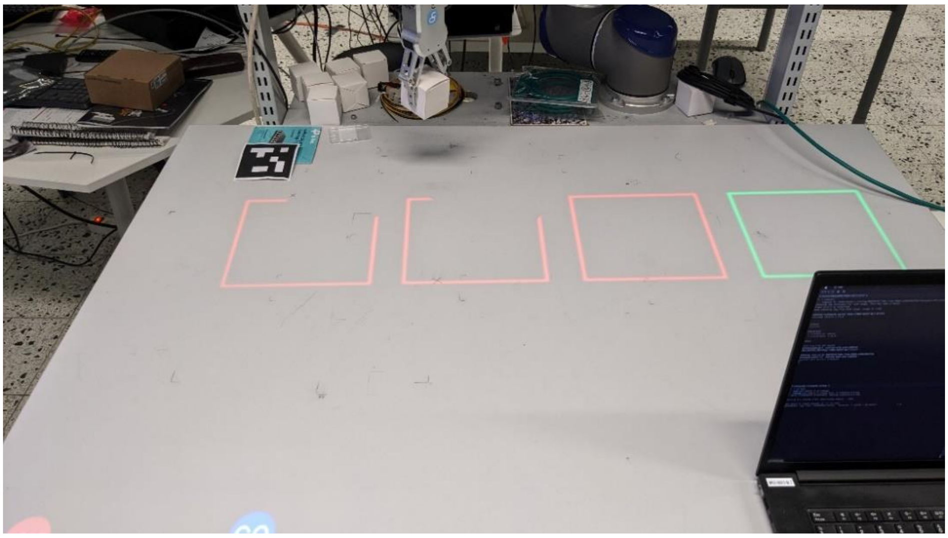


Figure 55: The second border from the left is booked, which also trigger the booking of adjacent borders at its sides

Once the object is placed inside a border, the robot releases the booking and picks another transformer to place it inside another border. The system highlights the corresponding border in order to notify that the specific object (transformer) should be picked by the operator (Figure 56).

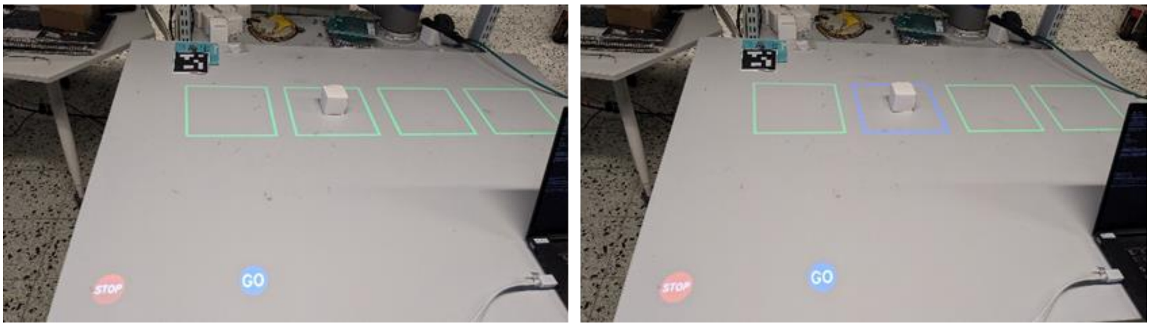


Figure 56: (Left) The robot releases the border booking, which states that it is safe for the operator to cross it. (Right) The system notifies the operator with blue border that the transformer should be picked from that location.

7.1.2. TAU HRC Pilot Line

Regarding the TAU's HRC pilot line, the system must also be correctly calibrated in order to display the smart user interface accurately. After calibration, the system can display the smart interface on any surface. In addition, the interface can be displayed on a moving surface such as a table. The system tracks the location of the table through an ArUco marker and updates the projection on the table in real time. This is particularly practical for large industrial environment by providing more freedom and flexibility to the operator. The operator is able to interact at any time with the elements displayed on the table by hovering his/her hand on them (Figure 57).

Figure 57: The smart interface is displayed on a table. The operator can interact with the displayed elements and control the robot operations.

The operator is also endowed with a safety feature regarding the robot. Indeed, a dynamic safety line is projected on the floor around the robot. It represents a virtual line that the operator should not cross, or this will trigger the safety stop of the robot's operation.

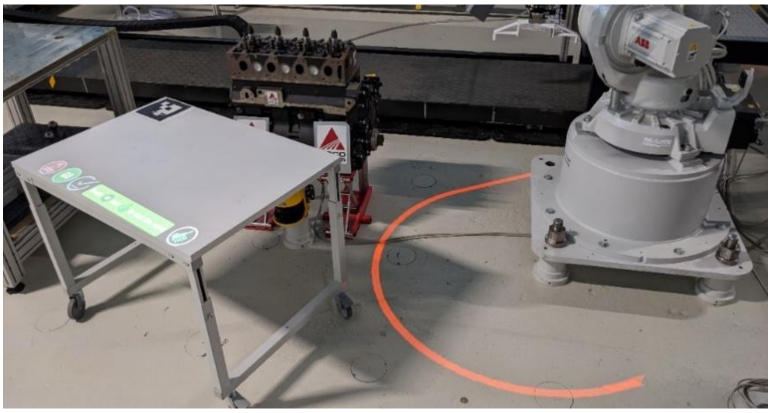


Figure 58: Red dynamic safety line projected around the robot.

The safety line is updated in real time according to the joint positions of the robot, and crossing of it is monitored by RGB-D camera(s) over the workstation.

7.2. VR Safety Training

In case of VR safety training two different use cases are discussed. First one is TAU small scale pilot called HRC Pilot line, which focuses on applications like ODIN automotive use case. The second is the preliminary phases and already starting preparations for ODIN White Goods use case as described in deliverable D5.4.

7.2.1. TAU HRC Pilot line

VR safety training is targeted to the application of human robot collaborative (HRC) operation in assembly of a diesel engine between heavier industrial robot and the operator in TAU's heavy laboratories. The design of system integrates multiple standards regarding robotics work cell design and safety design of system. As a result, after consideration of risk assessment and risk reduction process, collaborative operation is set to speed and separation monitoring. Regarding this collaboration level, laser scanner is utilized as a safety device to fulfil requirement for safety distances and areas definition. In this case, virtual reality safety training is developed to provide a safe environment for operators to acknowledge information in two phases regarding safety measures and assembly procedures. Safety measures that are included in this application consists of hazardous areas, robot workspace, and light indicators.

3D visual representation is considered as main goal to demonstrate intangible information that the operator could not perceive in real robotic work cell. Hazardous area is developed to depict the laser scanner safety areas in assembly operation. These borders are visualized by arc shape in our case, and they are interactive raising walls. They do demonstrate the timeline of triggering event for safety device, which could lead to reduce speed or stop of robot (Figure 59).

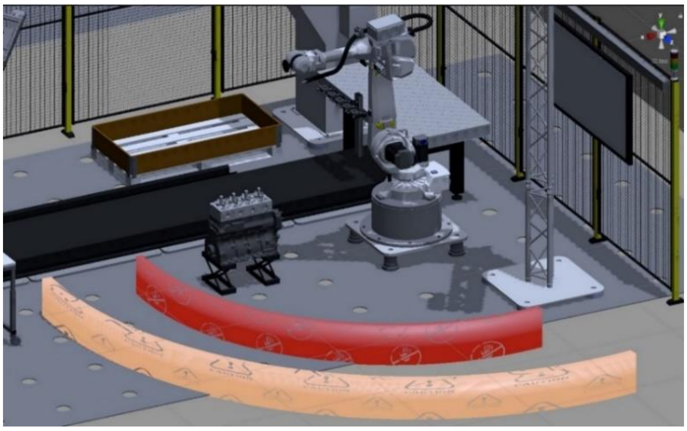


Figure 59: Representation of safety areas of laser scanner

Additionally, robot working space is shown by 3D sphere with expanding animation to demonstrate the reachability of robots' movement (Illustrated in Figure 60). In parallel, required information are presented through 3D UI. Operator could follow and refer back to this information at any time of their training. UIs guide operator regarding triggering events, which the user could face in real environment. In addition, UIs provide instructions how to react and avoid hazardous events (Figure 61).

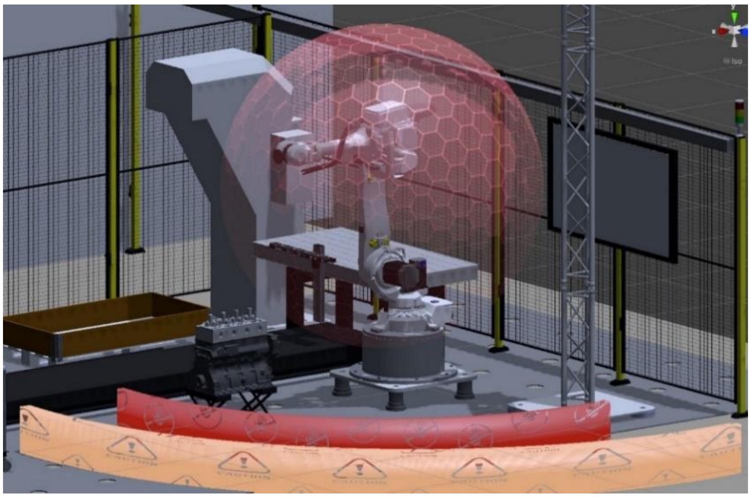


Figure 60: Robots' workspace visualization

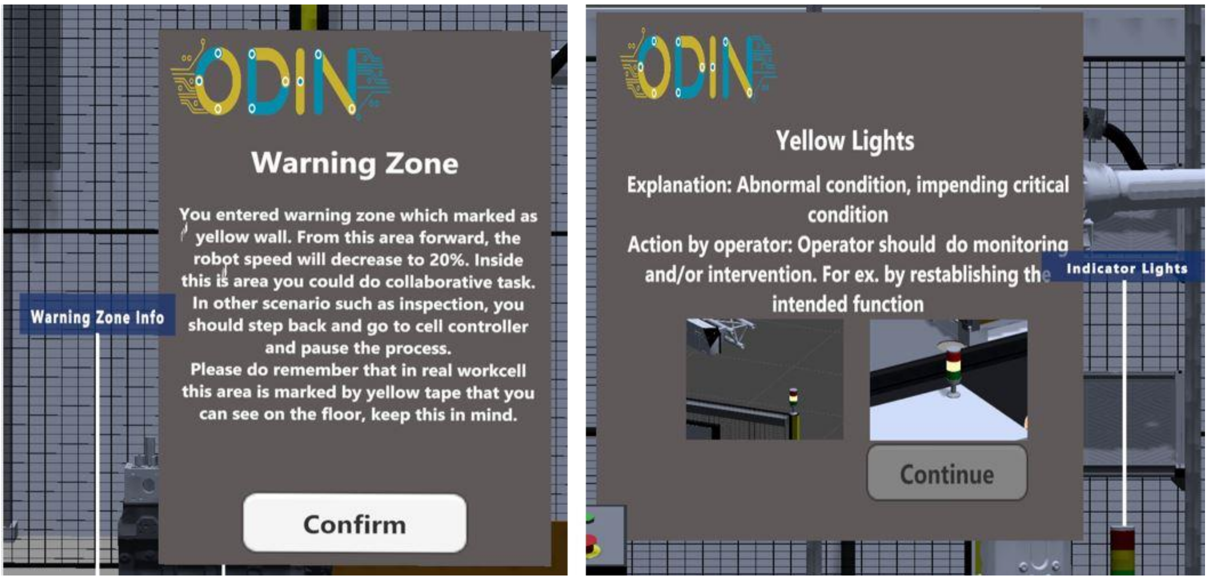


Figure 61: UIs instruction for safety measures

Light indicator is applied in robotic work cell to raise awareness of operator regarding the status of robotics' system. The colour coding of green, yellow, and red is referenced to normal, abnormal, and emergency situation respectively based on standards. Based on safety distances and presence of operator in different areas, proper light will be activated to let user be aware of safety measure alongside of others information. The similar light tower and coding is used in the real environment during operation.

At second phase, user follows UI instruction to proceed with assembly of engines' parts including rocker arms and pushrods. For this stage, another visualization is developed to assist user for better understanding of location of parts. Therefore, place holders for parts with colour coding are utilized to show when parts are placed in correct position. Alongside of users' tasks, robots' tasks are presented with animations for user to familiarize themselves with robots' trajectory and assembly processes (Figure 62).

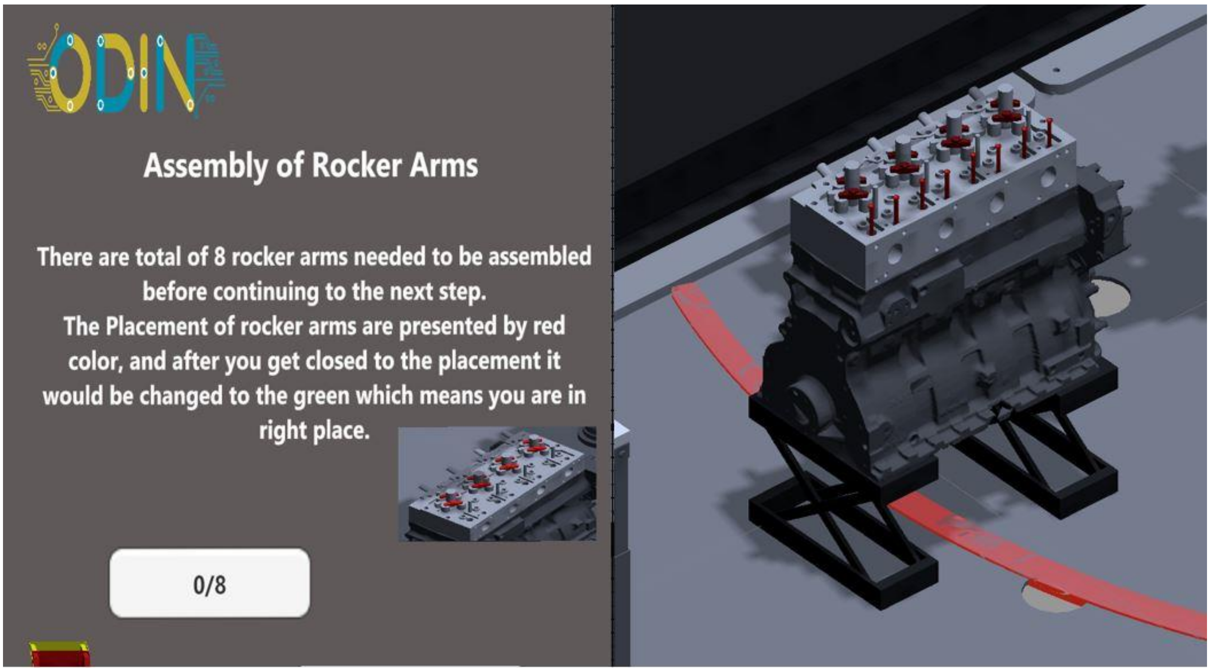


Figure 62: Assembly stage, Left: UI instruction - Right: Components' placeholders

8. CONCLUSIONS

This document presented the validation of Open Component modules as presented in D2.4 and D2.5 in the different small-scale pilots of ODIN at partners' facilities. The Open Component modules are focused on the following technologies investigated under ODIN:

- Reconfigurable robot tools,
- Smart human side interfaces,
- Robotic perception for the environment and process,
- Autonomous mobile manipulators,
- User friendly robot programming interfaces,
- Robotic perception for the human.

This deliverable is the continuation of previously submitted deliverable D2.3. The aforementioned technologies have been tested and validated in several small-scale pilots prepared at technology partners facilities namely LMS, TECNALIA, AIC, KTH and TAU. Additionally, the activities towards the safety validation of LMS, TECNALIA and AIC small scale pilots led by PILZ are detailly presented in the deliverable.

9. Glossary

AR	Augmented Reality
ASF	Automotive Smart Factory
EC	European Commission
EU	European Union
GUI	Graphical User interface
HMI	Human Machine Interface
HRC	Human Robot Collaboration
HRI	Human Robot Interaction
ROS	Robot Operating System
UI	User Interface
VR	Virtual Reality
WP	Work Package

10. References

1. ROBOCEPTION RC_Visard 65 camera sensor, [Online]. Available: https://roboception.com/product/rc_visard-65-monochrome/.
2. COMAU Agile, [Online]. Available: https://www.comau.com/en/competencies/robotics-automation/collaborative-robotics/automatic-guided-vehicles-agv/
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ANNEX 1: Preliminary verifications for small scale pilots – LMS Automotive Small-Scale Pilot

Preliminary Verifications for Small Scale Pilots

LMS Automotive Small-Scale Pilot

Report issued by:

Pilz Industrieelektronik S.L.

Camí Ral, 130 - Pol. Ind. Palou Nord

11. DOCUMENT STATUS

Document:	ODIN_D2.6 Draft-V2.docx

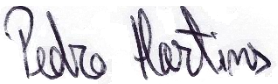
11.1. Revision history

Revision	Date	Reviewed by	Title/Function	Description of change
RevA	05/09/2022	Pedro Martins	Automation Engineer	Internal review
RevB	25/07/2023	Gonzalo Garcia	Automation Engineer	5th GA Pilot Verification
RevC	15/12/2023	Gonzalo Garcia	Automation Engineer	Small Scale Pilot Verification

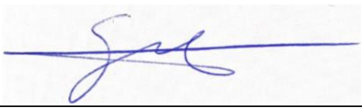
11.2. Document signatures

Signatures on this page indicate that this document has been reviewed, checked and approved by the concerned persons.

Author:

	22/06/2023
Pedro Martins / Automation Engineer - PILZ Signature by the PILZ engineer responsible for preparing the document.	**Date**

Reviewed By:

	25/07/2023
Gonzalo Garcia / Automation Engineer - PILZ Signature by the PILZ engineer responsible for reviewing the document.	**Date**

12. INTRODUCTION

This document serves as a comprehensive guide for the preliminary verification of the ***Automotive Pilot Case*** small scale pilot, which aims to conduct a thorough assessment of the safety aspects associated with the equipment, hazards, and overall safety concepts. By systematically going through the checklists provided, we can effectively identify any potential risks or gaps in our analysis, enabling us to make informed decisions and take appropriate actions to mitigate those risks. The verification process involves three checklists to ensure the necessary safety measures are in place.

The first section in this document presents a list of the equipment to be used during the small-scale pilots. It serves as a reference point to verify that all necessary tools and resources are readily available and in proper working conditions.

The second section is dedicated to identifying potential hazards associated with the small-scale pilot. By analyzing these risks, preventive measures can be implemented, and improvement plans can be developed to guarantee that all the safety requirements are obtained.

The third section validates the safety concepts developed for the small-scale pilot. It enables us to assess the effectiveness and adequacy of the safety measures we have implemented. Through this verification process, we can confirm that our safety concepts align with industry standards and best practices.

13. LIST OF REFERENCE DOCUMENTATION

No.	Description
1	ODIN D2.1_Final Version
2	ODIN D2.3 Final Version
3	ODIN D5.1_Final Version
4	ODIN-SafetyConcept-AutomotivePilotCase
5	ODIN-RA-AutomotivePilotCase-V0
6	AUTO - SC Implementation Details
7	ODIN-Automotive pilot case _Tooling configuration

14. Equipment Installation

It is essential to define the hardware architecture and the list of components that are proposed for the small-scale pilot in order to implement the safety concepts. Only the operation 1 (Motor and Gearbox Assembly) and operation 3 (Inspection) will be considered and simulated, so the TECNALIA mobile platform and the conveyor will not be assessed for now under this small-scale pilot.

14.1. Standard Equipment Checklist

No.	Description	OK	NOK	N/A
AUTO-BUC-01				
1	AURA Robot	☒	☐	☐
2	Hand Guidance Support	☒	☐	☐
3	Gripper 1 - Motor	☒	☐	☐
4	Gripper 2 - Gearbox	☒	☐	☐
AUTO-BUC-03				
5	COMAU Agile 1500 Mobile Platform	☒	☐	☐
6	COMAU Racer 5 Robot	☒	☐	☐

14.2. Safety Equipment Checklist

No.	Description	OK	NOK	N/A
AUTO-BUC-01				
1	1x Safety PLC + IO Modules (PSS4000)	☒	☐	☐
2	1x ESTOP Push-Button (PITestop)	☒	☐	☐
3	1x Light Barriers + Mirrors (PSENop)	☒	☐	☐
4	2x Scanner (PSENscan)	☒	☐	☐
5	1x Mode Selector + 2x Keys (PITreader)	☒	☐	☐
6	2x Enable Switch (Hand Guidance)	☒	☐	☐
7	8x Inductive Sensors (Gripper)	☒	☐	☐
8	4x Electro Valves (Gripper)	☒	☐	☐
9	2x Reset Push-Buttons	☒	☐	☐
10	2x ~~Gripper~~ Push-Buttons	☒	☐	☐
11	1x Status Indicator	☒	☐	☐
12	1x Light and Sound Beacon	☒	☐	☐
AUTO-BUC-03				

13	1x Safety PLC (PSS4000)	☒	☐	☐
14	2x Ethernet Bridge (R3 EchoRing)	☒	☐	☐
15	2x Photoelectric Sensors (WL2S-2P3230S09)	☒	☐	☐
16	1x Light / Sound Beacon	☒	☐	☐

15. HAZARD IDENTIFICATION

A design stage risk assessment was performed during the design phase of the project and documented in D5.1, together with a safety concept that provides the guidelines to eliminate and reduce these risks (for more information check the section 4.1 - Identified Hazards and Evaluation of the D5.1). For the initial prototype design that will be developed at LMS premises, only some of these hazards will be considered due to the number of equipment used. A checklist with the considered hazards is presented below.

15.1. Hazard Checklist

No.	Description	OK	NOK	N/A
AUTO-BUC-01				
1.1	Impact with the AURA Robot in conveyor area	☒	☐	☐
1.2	Impact with the AURA Robot in warehouse area	☒	☐	☐
1.4	Falling or ejection of the process part	☒	☐	☐
1.5	Crushing during the hand guidance operation	☒	☐	☐
AUTO-BUC-03				
2.1	Impact with the mobile platform during mobility	☐	☒2*	☐
2.3	Crushing between the mobile platform and the conveyor during approach	☒	☐	☐
2.5	Impact during movement caused by accessible parts of the machine	☒	☐	☐
2.9	Impact with the singe arm manipulator or tool during of inspection operation	☐	☒2*	☐
ALL BUC				
3.4	Failure of the safety related part of control system - Robots	☒	☐	☐
3.5	Failure of the safety related part of control system - End Effectors	☒	☐	☐
3.7	Failure of the safety related part of control system - Pneumatic System	☒	☐	☐
3.8	Unexpected movements due to new start-up	☒	☐	☐
3.9	Unexpected movements due to mode selection	☒	☐	☐
3.10	Inability to warn about status of Robot	☒	☐	☐

16. SAFETY CONCEPT

Due the nature of the initial prototype, some of the safety concepts that have been proposed in D5.1 need to be adapted in accordance with the layout provided by LMS. The objective of this adaptation is to allow a detailed understanding of the proposed safety solutions for the small-scale pilot that will be tested in LMS premises. These solutions are presented to ensure the machine complies with the mechanical, electrical, pneumatic and control requirements in this first phase of the project. A small description of the changes is provided bellow (for more information on the requirements for each function check the section 4.2 - Safety Concepts of the D5.1), together with a checklist for the different requirements.

16.1. AURA Robot Autonomous Operation – SSM (4.2.1)

The safety scanners will be installed in the lateral parts of the assembly table to provide coverage to the interior of the cell. The safety areas will be adjusted in depending on the lab dimensions. All the other associated functions remain the same.

No.	Description	OK	NOK	N/A
1	The two safety scanners have been installed properly	☒	☐	☐
2	Distance to hazard points is in accordance to ISO 13855	☒	☐	☐
3	Different zones have been programmed for the scanners	☒	☐	☐
4	Movement of the robot is stopped when in hazard area	☒	☐	☐
5	The speed of AURA Robot is adapted depending on the area	☒	☐	☐
6	The speed of AURA Robot is adapted depending on the area	☒	☐	☐
7	Embedded safety functions are applied to limit reachability	☒	☐	☐

16.2. Access From Infeed Area (4.2.2)

The light barriers will be installed around the layout of the prototype to provide coverage to the interior of the cell. The exact location will be adjusted depending on the lab dimensions. There is no need to install a muting lamp. All the other associated functions remain the same.

No.	Description	OK	NOK	N/A
1	The pair of light barriers and mirrors was installed properly	☒	☐	☐
2	Distance to hazard points is in accordance to ISO 13855	☒	☐	☐
3	Movement of the robot is stopped if barriers are interrupted	☒	☐	☐
4	A manual reset is needed after the interruption of movement	☒	☐	☐

16.3. Safe monitoring of the parts grasping (4.2.3)

The parts for the pneumatic grippers used for the grasping of the motor and gearbox need to be selected, tested and properly installed. The locking actuation must be managed under safety criteria since during the blockade itself there is exposure of the operator, and an unexpected unlocking must be prevented. All the other associated functions remain the same.

No.	Description	OK	NOK	N/A
1	The interlocking system of the gripper is intrinsically safe	☒	☐	☐
2	A redundant solenoid valve has been installed in the gripper	☒	☐	☐
3	Pressure switch have been installed to monitor the status	☒	☐	☐
4	Under pressure switch has been installed to prevent start-up	☒	☐	☐
5	Magnetic sensors have been installed in the cylinders	☒	☐	☐
6	The circuits are designed considering the exclusion of failure	☒	☐	☐

16.4. Hand-guiding operation (4.2.4)

The special gripper for the manual operation of the part using hand guidance needs to be installed, we should be able to simulate this functionality in full. The gripper will enable the movement of the robot with the gearbox if both enable switch are pressed. All the other associated functions remain the same.

No.	Description	OK	NOK	N/A
1	The enable switch devices have been installed properly	☒	☐	☐
2	Ergonomic hazards were avoided in the gripper design	☒2*	☐	☐
3	The robot movement is only enabled when switch is active	☒	☐	☐
4	The hand guidance can only be used with mode selector	☒	☐	☐
5	The gripper push-buttons are installed outside hazard area	☒	☐	☐
6	Release of process part is only allowed in restricted volume	☒	☐	☐

16.5. Emergency Stop (4.2.5) and Interconnection of SRP/CS of mobile platform and collaborative manipulators (4.2.10)

There is no need to install multiple ESTOP Push-Buttons in the prototype, one in the controller station is enough. It is also important to test the safe wireless communication between the mobile platform and the cell. All the other associated functions remain the same.

No.	Description	OK	NOK	N/A
1	The ESTOP Push-Button has been installed properly	☒	☐	☐
2	If the button is pressed all dangerous actuators are stopped	☒	☐	☐
3	The R3 Echo Ring devices have been properly installed	☐	☐	☒

4	Interconnection between devices is working in accordance	☐	☐	☒
5	In case of connection failure, there is an immediate stop	☒	☐	☐

16.6. Operating mode selection (4.2.6)

An external mode selector shall be provided which can be locked in each mode position. The operating mode selector should be installed outside the hazard area of the robot. The operating modes for the small scale pilot should be automatic, manual and hand guidance. All the other associated functions remain the same.

No.	Description	OK	NOK	N/A
1	Mode selector has been installed properly	☒	☐	☐
2	The mode selector has been outside the hazard area	☒	☐	☐
3	After a mode change, the system needs a manual reset	☒	☐	☐
4	Automatic mode only works with all safety devices enabled	☒	☐	☐
5	Hand-guidance mode only works with both enable switches	☒	☐	☐

16.7. Mobile Platform Operation (4.2.7)

For this operation it is important to properly configure the scanners fields installed in the mobile platform to be adapted to the lab dimensions and space in order to avoid dangerous collision with operators and other objects. All the other associated functions remain the same.

No.	Description	OK	NOK	N/A
1	The laser scanners have been installed properly	☒	☐	☐
2	Fields of the mobile platform have been adapted properly	☒1*	☐	☐
3	Protective stop is triggered after the detection of a person	☒	☐	☐
4	Movement of the robot is disabled when platform is moving	☒	☐	☐
5	All parts of the robot are inside the platform when moving	☒	☐	☐
6	Light indicator has been programmed to different operations	☒	☐	☐
7	Guidelines from EN ISO 3691-4 are followed in navigation	☒	☐	☐

16.8. Mobile platform operations linked to conveyor (4.2.8) and Collaborative mobile manipulators operation – SSM (4.2.9)

In this case we are only simulating the inspection operation, so there is no need to consider the hazards screwing while moving operation. It is important to test the conveyor approach solution, even though this will be a static operation. There is no need to install a new scanner in the mobile platform, the fields can be changes using a zone set. All the other associated functions remain the same.

No.	Description	OK	NOK	N/A
1	Optoelectronic sensors have been installed properly	☒	☐	☐
2	Trigger of the muting function is done in a safe way	☒	☐	☐
3	Coupling between the AGV and the table is well detected	☒	☐	☐
4	Interconnection of ESTOPs works with coupling active	☒	☐	☐
5	Scanner is adapted to robot movement with coupling active	☒	☐	☐

17. Punch List

Any incomplete task or non-conformity shall be recorded on the punch list and categorized as follows:

A → Accepted

B → Rejected

C → To be rectified for Small Scale Pilot

D → To be rectified for Final Pilot

No.	Description	Responsible	Type	Complete
1	Safety areas do not cover the whole mobile manipulator. However, there is not significant risk resulting from this.	LMS / PILZ	**D**	
2	Gripper is installed in 90 degrees because the hand-guidance operation requires a different angle. One enable switch and two push-buttons is OK.	/	**A**	

ANNEX 2: Preliminary verifications for small scale pilots – LMS White Goods Small-Scale Pilot

Preliminary Verifications for Small Scale Pilots

LMS White Goods Small-Scale Pilot

Report issued by:

Pilz Industrieelektronik S.L.

Camí Ral, 130 - Pol. Ind. Palou Nord

Project: ODIN

Document: PILZ - White Goods Pilot Case - Preliminary Verifications

18. DOCUMENT STATUS

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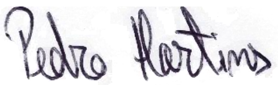
18.1. Revision history

Revision	Date	Reviewed by	Title/Function	Description of change
RevA	05/09/2022	Pedro Martins	Automation Engineer	Internal review
RevB	25/07/2023	Gonzalo Garcia	Automation Engineer	5th GA Pilot Verification
RevC	15/12/2023	Gonzalo Garcia	Automation Engineer	Small Scale Pilot Verification

18.2. Document signatures

Signatures on this page indicate that this document has been reviewed, checked and approved by the concerned persons.

Author:

	06/06/2023
Pedro Martins / Automation Engineer - PILZ Signature by the PILZ engineer responsible for preparing the document.	**Date**

Reviewed By:

	25/07/2023
Signature by the PILZ engineer responsible for reviewing the document.	**Date**

19. INTRODUCTION

This document serves as a comprehensive guide for the preliminary verification of the ***White Goods Pilot Case*** small scale pilot, which aims to conduct a thorough assessment of the safety aspects associated with the equipment, hazards, and overall safety concepts. By systematically going through the checklists provided, we can effectively identify any potential risks or gaps in our analysis, enabling us to make informed decisions and take appropriate actions to mitigate those risks. The verification process involves three checklists to ensure the necessary safety measures are in place.

The first section in this document presents a list of the equipment to be used during the small scale pilots. It serves as a reference point to verify that all necessary tools and resources are readily available and in proper working condition.

The second section is dedicated to identifying potential hazards associated with the small scale pilot. By analyzing these risks, preventive measures can be implemented, and improvement plans can be developed to guarantee that all the safety requirements are obtained.

The third section validates the safety concepts developed for the small scale pilot. It enables us to assess the effectiveness and adequacy of the safety measures we have implemented. Through this verification process, we can confirm that our safety concepts align with industry standards and best practices.

20. LIST OF REFERENCE DOCUMENTATION

No.	Description
1	ODIN D2.1_Final Version
2	ODIN D2.3 Final Version
3	ODIN D5.1_Final Version
4	ODIN-SafetyConcept-White GoodsPilotCase
5	ODIN-RA-White GoodsPilotCase-V0
6	WHR - SC Implementation Details

21. EQUIPMENT INSTALLATION

It is essential to define the hardware architecture and the list of components that are proposed for the small scale pilot in order to implement the safety concepts. All the operations will be considered and simulated in the small scale pilot, except the moving conveyor that will be simulated with a static table.

21.1. Standard Equipment Checklist

No.	Description	OK	NOK	N/A
1	UR10 Robot + Accessories	☒	☐	☐
2	Gripper 1 - Magnetic	☒	☐	☐
3	Gripper 2 - Adaptative	☒	☐	☐
4	Gripper 3 – Pneumatic	☒	☐	☐

21.2. Safety Equipment Checklist

No.	Description	OK	NOK	N/A
1	1x Safety PLC + IO Modules (PSS4000)	☒	☐	☐
2	1x ESTOP Push-Button (PITestop)	☒	☐	☐
3	2x Light Barriers (PSENop)	☒	☐	☐
4	1x Magnetic Sensor (PSENcode)	☒	☐	☐
5	1x Reset Push-Buttons	☒	☐	☐
6	1x Status Indicator	☒	☐	☐
7	1x Light and Sound Beacon	☒	☐	☐

22. Hazard Identification

A design stage risk assessment was performed during the design phase of the project and documented in D5.1, together with a safety concept that provides the guidelines to eliminate and reduce these risks (for more information check the section 6.1 - Identified Hazards and Evaluation of the D5.1). For the initial prototype design that will be developed at LMS premises, only some of these hazards will be considered due to the number of equipment used. A checklist with the considered hazards is presented below.

22.1. Hazard Checklist

No.	Description	OK	NOK	N/A
1.1	Impact with the Robot in operator area	☒	☐	☐
1.2	Impact with the Robot in back area	☒	☐	☐
1.3	Impact with the process part during placement	☒	☐	☐
1.4	Impact during the pallet change operation	☒	☐	☐
1.5	Falling or ejection of the process part	☒	☐	☐
1.9	Impact with the robot during teaching operation	☒	☐	☐
1.11	Robot movements beyond the expected boundaries	☒	☐	☐
1.13	Hazards generated by the loss of end effector	☒	☐	☐
2.3	Failure of the safety related part of control system - Robot	☒	☐	☐
2.4	Failure of the safety related part of control system - End Effector	☒	☐	☐
2.7	Unexpected movements due to new start-up	☒	☐	☐
2.8	Unexpected movements due to mode selection	☒	☐	☐
2.9	Inability to warn about status of Robot	☒	☐	☐

23. SAFETY CONCEPT

Due the nature of the initial prototype, some of the safety concepts that have been proposed in D5.1 need to be adapted in accordance with the layout provided by LMS. The objective of this adaptation is to allow a detailed understanding of the proposed safety solutions for the small-scale pilot that will be tested in LMS premises. These solutions are presented to ensure the machine complies with the mechanical, electrical, pneumatic and control requirements in this first phase of the project. A small description of the changes is provided bellow (for more information on the requirements for each function check the section 6.2 - Safety Concepts of the D5.1), together with a checklist for the different requirements.

23.1. Collaborative approach – front area (6.2.1)

This concept involves safely dividing the robot's working space into two distinct areas: the frontal area and the back area. This allows the robot to work continuously in method 4 in a fenceless environment, using internal safety functions such as Safety Planes or Joint Position Limit will be employed for this purpose. All the other associated functions remain the same.

No.	Description	OK	NOK	N/A
1	Working space of the robot is divided in two different areas	☒	☐	☐
2	Speed of the robot is changed depending on the area	☒	☐	☐
3	Distance to back area is in accordance to ISO 13857	☐	☒1*	☐
4	Impact measurements are in accordance to ISO 15066	☒	☐	☐
5	Movement of the robot is stopped when contact is made	☒	☐	☐
6	A manual reset is needed after the interruption of movement	☒	☐	☐
7	Embedded safety functions are applied to limit reachability	☐	☒1*	☐

23.2. Collaborative approach – back area (6.2.2) and Access monitoring of the back area (6.2.3)

This was proposed to allow the operator to change the pallets without stopping the robot. Initially, the loading area was divided in two different zones but due to limitations on the robot this concept was not possible to implement. To achieve this, the access to the loading area is safely monitored by the light barriers and the robot will work on collaborative mode unless a hazard gripper is attached. All the other associated functions remain the same.

No.	Description	OK	NOK	N/A
1	The two pairs of light barriers are installed properly	☒	☐	☐
2	Robot stops if barriers are interrupted (G3 attached)	☒	☐	☐
3	Robot reduces speed if barriers are interrupted (G1/G2)	☒	☐	☐
4	Distance to hazard points is in accordance to ISO 13855	☐	☒1*	☐
5	Impact measurements are in accordance to ISO 15066	☒	☐	☐
6	Disable robot movement in the zone barriers are interrupted	☒	☐	☐

7	A manual reset is needed after the interruption of barriers	☒	☐	☐
8	Light indicator has been programmed to different operations	☒	☐	☐

23.3. Safe monitoring of vacuum gripper attached to the robot (6.2.4)

Due to the hazards related to the pneumatic gripper, there is the need to monitor it's presence with a safe magnetic sensor. If the pneumatic gripper is attached to the robot, some additional logic for the cell operation needs to be implemented. This kind of sensor could be coded, so if the actuating part is changed it does not allow a safe position detection. All the other associated functions remain the same.

No.	Description	OK	NOK	N/A
1	The safe magnetic sensor and actuator are installed properly	☒	☐	☐
2	If the gripper is attached, logic of back area access changes	☒	☐	☐
3	Robot stops if barriers are interrupted with sensor detected	☒	☐	☐
4	The robot can't go to frontal area with this gripper attached	☒	☐	☐

23.4. Operating mode selection (6.2.5)

To address unusual situations and facilitate hand-guiding or teaching operations, a mode selector was initially planned. Due to the availability of a mode selection function in the teach pendant of the robot, an additional mode selector was not considered if the safety requirements for other functional modes are fulfilled. All the other associated functions remain the same.

No.	Description	OK	NOK	N/A
1	Automatic mode only works with all safety devices enabled	☒	☐	☐
2	After a mode change, the system needs a manual reset	☒	☐	☐
3	Safety configurations remain active using other modes	☒	☐	☐
4	Speed reduced if manual modes are selected in the robot	☒	☐	☐
5	Mode selection is disabled if vacuum gripper is attached	☒	☐	☐
6	Impossibility to change the speed for manual modes	☒	☐	☐
7	When using OpenFlow safety configurations remain active	☒	☐	☐

23.5. Gripper Designs (6.2.6)

The avoidance of sharp edges and use of soft materials is important for the collaborative operation of the robot in order to minimize the impact pressure on the operator. The magnetic and adaptative grippers should fulfil some requirements to avoid dropping of the process part. The vacuum gripper will be considered as hazard and the robot will not work in collaborative mode. Initially a soft-start soft-start/quick exhaust valve was considered too, but no movable pneumatic parts will be included in the actual designs. All the other associated functions remain the same.

No.	Description	OK	NOK	N/A
1	The magnetic gripper has been installed properly	☒	☐	☐
2	The adaptative gripper has been installed properly	☒	☐	☐
3	The pneumatic gripper has been installed properly	☒	☐	☐
4	Collaborative grippers don’t present sharp edges on designs	☒	☐	☐
5	Soft materials have been used to reduce impact pressure	☒	☐	☐
6	Impact measurements for grippers were performed and OK	☒	☐	☐
7	Part is not released after power loss in magnetic gripper	☒	☐	☐
8	Part is not released after pressure loss in adaptative gripper	☒	☐	☐
9	Part is not released after pressure loss in pneumatic gripper	☒	☐	☐
10	Additional diagnostic signals have been used for grippers	☒	☐	☐
11	Tool change operation is only possible with light barriers free	☒	☐	☐

23.6. Emergency Stop (6.2.7)

Two ESTOP Push-Buttons need to be installed, one in the frontal part of the cell and one in the back part of the cell. The buttons should be connected in dual channel architecture to the safety controller and disconnect the dangerous actuators of the machine when pressed. All the other associated functions remain the same.

No.	Description	OK	NOK	N/A
1	The ESTOP Push-Button has been installed properly	☒	☐	☐
2	If the button is pressed all dangerous actuators are stopped	☒	☐	☐

24. PUNCH LIST

Any incomplete task or non-conformity shall be recorded on the punch list and categorized as follows:

A → Accepted

B → Rejected

C → To be rectified for Small Scale Pilot

D → To be rectified for Final Pilot

No.	Description	Responsible	Type	Complete
1	To be studied with real pilot and VC simulation. It is possible to use boundaries programmed in the robot to limit the movement.	PILZ / LMS	**C, D**	

ANNEX 3: Preliminary verifications for AIC small scale pilot

Preliminary Verifications for Small Scale Pilots

AIC Case

Report issued by:

Pilz Industrieelektronik S.L.

Camí Ral, 130 - Pol. Ind. Palou Nord

Project: ODIN

Document: PILZ - Automotive Pilot Case - Preliminary Verifications

25. DOCUMENT STATUS

Document:	PILZ - AIC Case - Preliminary Verifications

25.1. Revision history

Revision	Date	Reviewed by	Title/Function	Description of change
RevA	16/10/2023	Ramon Tresguerres	Consulting	Internal review
RevB				
0				

25.2. Document signatures

Signatures on this page indicate that this document has been reviewed, checked and approved by the concerned persons.

Author:

Ramón Tresguerres	16/10/2023
Ramón Tresguerres / Consulting Services - PILZ Signature by the PILZ engineer responsible for preparing the document.	**Date**

Reviewed By:

Daniel Martín Mañas / Competence Center - PILZ Signature by the PILZ engineer responsible for reviewing the document.	**Date**

26. INTRODUCTION

This document serves as a comprehensive guide for the preliminary verification of the ***AIC Case*** small scale pilot, which aims to conduct a thorough assessment of the safety aspects associated with the equipment, hazards, and overall safety concepts. By systematically going through the checklists provided, we can effectively identify any potential risks or gaps in our analysis, enabling us to make informed decisions and take appropriate actions to mitigate those risks. The verification process involves checklists to ensure the necessary safety measures are in place.

The first section in this document presents a list of the equipment to be used during the small scale pilots. It serves as a reference point to verify that all necessary tools and resources are readily available and in proper working condition.

The second section is dedicated to identifying potential hazards associated with the small scale pilot. By analyzing these risks, preventive measures can be implemented, and improvement plans can be developed to guarantee that all the safety requirements are obtained.

27. LIST OF REFERENCE DOCUMENTATION

No.	Description
1	ODIN D2.1_Final Version
2	ODIN D2.3 Final Version
3	ODIN D5.1_Final Version
4	ODIN-SSP AIC SafetyConcept (draft)

28. Equipment Installation

It is essential to define the hardware architecture and the list of components that are proposed for the small scale pilot in order to implement the safety concepts. Only the operation 3 (Motor and Gearbox Inspection) will be considered and simulated.

With the following equipment, the operating cycle is as follows. The initial condition is that the ASF equipment with ABB Robot located in its workstation and coupled to the system through the connections provided for this purpose:

1) Conveyor C closes from its standby or non-operational position until it is perpendicular to conveyor A, leaving the ASF+Robot ABB unit closed in a U-shaped zone.
2) The motor or gearbox, coming from the previous process and placed on conveyor A (crane, forklift or other means of handling), travels from A to the opposite end of the rotary conveyor C.
3) The motor or gearbox returns to conveyor A while the ABB Robot takes the appropriate motor pictures, according to its operating program. The robot paths never exceed the 2 vertical planes containing both the central and horizontal axis of conveyors A and C.
4) After arrival at conveyor A, the motor starts another cycle, this time making a pass through conveyor B, which executes a change of orientation so that the ABB robot can photograph the other side.
5) The cycle ends when the motor reaches conveyor A again and the conveyor C opens, releasing the U-shaped zone and allowing the ASF+Robot ABB equipment to exit.

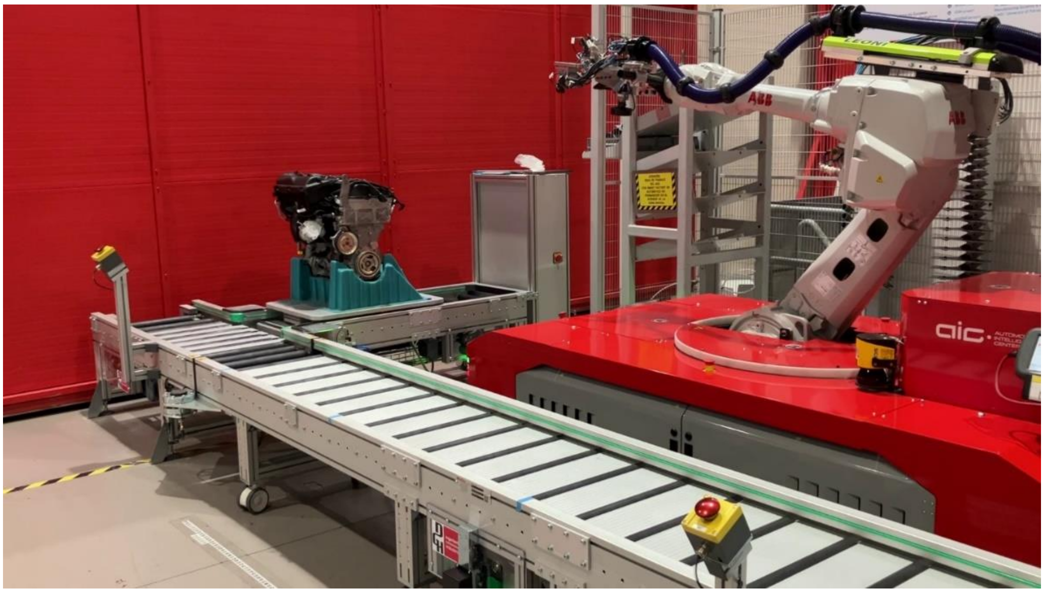
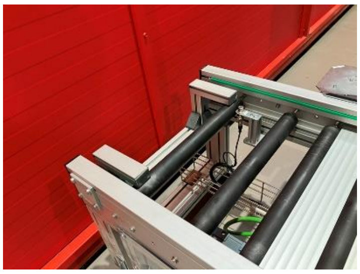
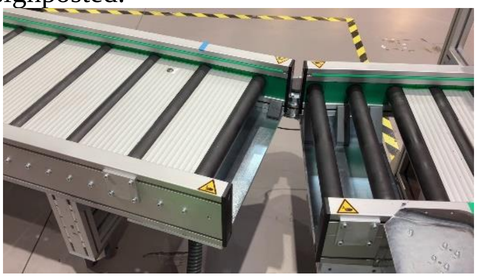
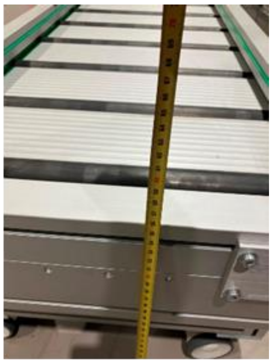


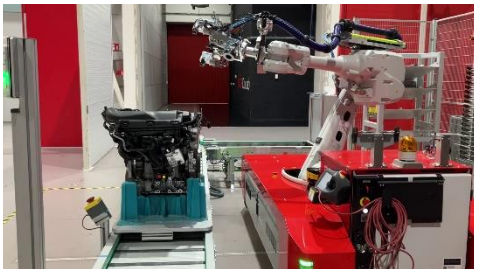
Figure 63: AIC Small scale pilot

28.1. Standard Equipment Checklist

	Description	OK	NOK	N/A
1	Conveyors A, B and C			
1.1	Conveyor drives are mechanically well protected, in accordance with EN 619 	☒	☐	☐
1.2	There are mechanical stops that prevent the motor from falling at the end of the trip, even in case of failure of the limit switch. 	☒	☐	☐
1.3	The free space from the end of path of conveyor C, in its rest or non-operational zone, to fixed points of the building structure (wall), is 330 mm. EN ISO 13854 standard sets a minimum gap of 180 mm to avoid crushing with the leg (area of the body susceptible to being crushed). 	☒	☐	☐
1.4	The rotary motion of the conveyor C, in both directions, is very slow and has an acoustic and luminous warning before and during its closing and opening paths.	☒	☐	☐

No.	Description	OK	NOK	N/A
1.5	If an obstruction is placed in its path, for example a human body, the conveyor C does not have enough force to continue its path, even though it maintains the turn command. 	☒	☐	☐
1.6	There are two standardised mushroom emergency stop buttons, positioned so that it is not necessary to walk more than 5 metres to reach either of them. There is an additional button on the door of the control cabinet. All of them are located at a perfectly accessible and standardised height. Pressing either button stops all movements and de-energizes the actuators. 	☒	☐	☐
1.7	However, - There is an accessible hazard point at the closing point between conveyors B and C, in the inner part of the U-shaped area. This point is signposted. 	☐	☒ 1 or 3	☐

No.	Description	OK	NOK	N/A
1.8	- The height of the conveyor is 55 cm to the floor. This height is not coercive enough to make it sufficiently difficult for the robot to reach over the conveyor.  	☐	☒ 1 or 2	☐

No.	Description	OK	NOK	N/A
2	ASF + ABB robot. AGV with built-in ABB robot, intended to take pictures of the engine and gearbox.			
2.1	Intrinsic safety of the ASF + ABB robot assembly guaranteed by its CE certification (to be provided). Not part of this preliminary verification	☐	☐	☒
2.2	Safety laser scanners are intended to remain operational to monitor unauthorized access, even with static AGV. 	☒	☐	☐
2.3	Robot paths do not invade spaces likely to be occupied by people. At no time do they exceed vertical planes containing the horizontal and central axes of the conveyors. 	☒	☐	☐
2.4	The attachment of the robot to the griper appears to be robust and suitable for the intended use. 	☒	☐	☐

No.	Description	OK	NOK	N/A
2.5	However, Pending final programming of the detection fields:	☐	☒ 1	☐
2.5.1	- Of unauthorized approach or access through the open part of the U-zone. 	☐	☒ 1	☐
2.5.2	- Of unauthorized approach or access to a robot operating on conveyors, and even of crossings over the conveyors (see 1.8).	☐	☒ 1 or 2	☐

28.2. Safety Equipment Checklist

No.	Description	OK	NOK	N/A
1	SAFETY CONTROL HARDWARE			
	Siemens Simatic S71200 PLC for process signals and Wieland SNA4043K safety module for emergency stop control	☒	☐	☐
2	ESTOP PUSH-BUTTON			
	There are three emergency stop buttons, being sufficient	☒	☐	☐
	The stop command is mechanically locked and has to be released manually.	☒	☐	☐
	Manual reset is required before restarting after activation of the emergency stop.	☒	☐	☐
	Emergency signals have been wired in double channel and in series to the Weiland safety module, being possible to achieve PL=d	☒	☐	☐
	One channel fault is detected (according to wiring diagrams; test not performed and pending).	☐	☐	☒
3	SCANNER LASER			
3.1	Equipment according to standard EN 61496-3 (pending declaration of conformity according to 2006/42/EC)	☒	☐	☐
3.2	Intended to protect against unauthorized access from positions lacking other means of protection. (See 2.5.2 and 1.8)	☒	☐	☐
3.3	Appropriate number and positions.	☒	☐	☐
3.4	The absence of people inside the U-zone is guaranteed during the entire cycle, including the rotation of conveyor C, before any productive movement is initiated. (Depends on pending field programming)	☐	☒ 1	☐
3.5	Safety distances comply with EN ISO 13855, with documented supporting calculations. (Final programming pending)	☐	☒ 1	☐
3.6	Marked and visible safety distances.	☐	☒ 1	☐
3.7	Manual reset required after safety stop, prior to restart.	☒	☐	☐
3.8	Installation and operation according to specifications and regulatory requirements (PL=d). (Pending final installation. Not part of this preliminary verification)	☐	☐	☒

No.	Description	OK	NOK	N/A
4	MODE SELECTOR + KEYS (PITREADER)			
4.1	There are no modes of operation, regardless of where you run it from (according to Mikel) the process is the same. There is no maintenance or manual mode	☐	☐	☒
5	ENABLE SWITCH (HAND GUIDANCE)			
5.1	Robot part. Not part of this preliminary verification	☐	☐	☒
6	GRIPPER			
6.1	Robot part. Not part of this preliminary verification	☐	☐	☒
7	RESET PUSH-BUTTONS			
7.1	There is a specific and separate reset button	☒	☐	☐
7.2	Properly identified and colored blue	☒	☐	☐
7.3	Located in area with good visual control of hazard zones	☒	☐	☐
7.4	Manual actuation of the reset is required after each safety stop.	☒	☐	☐
7.5	Supervised manual reset. Test not performed and pending.	☐	☐	☐
8	MOTOR CONTROLLER			
8.1	Appropriate mounting in the cabinet, according to good practice	☒	☐	☐
8.2	Safety signals via dual-channel, thus making it possible to achieve PL=d	☒	☐	☐
8.3	One channel fault is detected (according to wiring diagrams; test not performed and pending).	☒	☐	☐
8.4	Current monitoring for obstacle safety works as intended. (Although the motor torque appears to be insufficient to cause damage, the motor does not stop, nor does it reverse direction, if an obstacle prevents the rotary conveyor from moving).	☐	☒ 4	☐
10	LIGHT AND SOUND BEACON			
10.1	Location in a visible area.	☒	☐	☐
10.2	Colour coding according to standard	☒	☐	☐
10.3	Acoustic device is clearly audible	☒	☐	☐
10.4	Warns of start-up prior to start of operation. The time before start-up is sufficient for a safe response.	☒	☐	☐

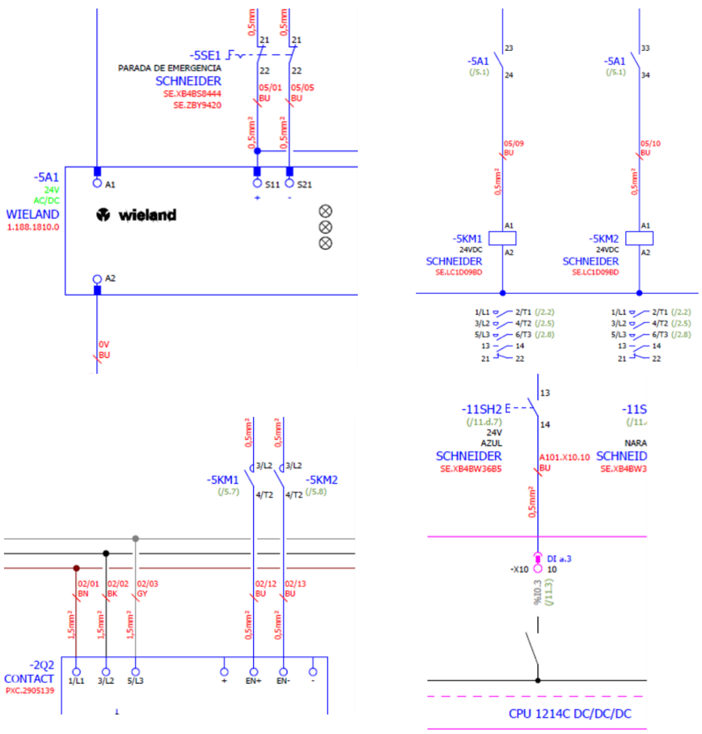
29. HAZARD IDENTIFICATION

A design stage preliminary risk assessment was performed during the design phase of the project and documented in D5.1, together with a safety concept that provides the guidelines to eliminate and reduce these risks (for more information check the section 4.1 - Identified Hazards and Evaluation of the D5.1). For the initial prototype design that will be developed at LMS premises, only some of these hazards will be considered due to the number of equipment used. A checklist with the considered hazards is presented below.

29.1. Hazard Checklist

No.	Description	OK	NOK	N/A
1.1	Mechanical contact during conveyor rotation. Impact, entrapment, crushing	☐	☒	☐
	Although the motor torque appears to be insufficient to cause damage, the motor does not stop, nor does it reverse direction, if an obstacle prevents the rotary conveyor from moving. The response of the PXC motor controller should be regulated to make the intended function operational.		See Punch List 4	
1.2	Crushing of hands in the closing area between conveyors B and C during the closing movement of C.	☐	☒	☐
	Although the movement is slow, warned and there are signs indicating the hazard, there is access to the indicated area with a risk of crushing from the area outside the conveyors. Two possible solutions are proposed: - Access zone will be controlled by a set of laser scanners, generating a response to unauthorized presence. - Provide a distancing structure in accordance with EN ISO 13857, preventing access by hands and fingers to the area in question.		See Punch List 1 3	
1.3	Mechanical contact due robot movements	☐	☒	☐
	The protection system to avoid contact with the robot and/or its gripper in movement is based on the programming of fields and the proper functioning of the set of laser scanners foreseen, which should be reprogrammed and validated.		See Punch List 1	
1.4	Impact with the single arm manipulator or tool during of inspection operation	☒	☐	☐
	The mounting of the griper appears to be robust. The robot does not leave its area to take photos on the outside. The operation does not require presence and, if the measures foreseen in 1.3 are functional, the presence will lead to a stop.			

No.	Description	OK	NOK	N/A
1.5	Falling or ejection of the process part	☒	☐	☐
	The motor housing bracket is stable, the trip movement is slow. The conveyors are equipped with limit sensors and mechanical stops that prevent the motor from falling at the end of the conveyor in case of failure of the first ones.			
1.6	Mechanical dangers due to possible passage of the conveyor C towards the robot.	☐	☒	☐
	The height of the conveyor, 55 centimetres, is not considered to be a constraint against overpassing it (see point 1.8 of section 4.1 of this report). Thus, the risks associated with accessing the robot above conveyor C by climbing on it must be considered. Two possible solutions are proposed: - Monitoring of the immediate area of the conveyor by means of the set of safety laser scanners provided. (see 1.2 of this section) - Attach fixed structures up to one metre in height to the external face of the conveyors, the purpose of which is to coerce the conveyor against the crossing. In this case, EN ISO 13854 must be taken into consideration in relation to the minimum distance to be respected between the mounted structure and the wall when the conveyor is in its rest position. See 1.3 of section 4.1 of this report		See Punch List 1 2	

No.	Description	OK	NOK	N/A
1.7	Failure of the safety related part of control system – Emergency Stop Functions	☒	☐	☐
	According to the provided schematics, the two channels that include the emergency mushroom contact series are connected to the inputs of the Wieland safety module, whose switching contacts disconnect the 5KM1 and 5KM2 contactors. These contactors redundantly control the enabling of the PXC2905139 motor controllers, generating a safe shutdown. However, The contactors 5KM1 and 5KM2 have two NC contacts (21-22) which are not wired. Thus, a possible failure in either of them is not monitored by the manual reset condition chain of the Safety Relay. Apparently, this diagnostic is done through the fault state in which the PXC2905139 controllers should remain and which the process PLC should recognize and prevent the reset being executed. Pending fault injection test. 	See Punch List 5		

No.	Description	OK	NOK	N/A
1.8	Failure of the safety related part of control system - Robots	☐	☐	☒
	It is considered to have PL=d + Cat3, according to standard, which will be supported by its manufacturer's certification. It is not part of this preliminary verification			
1.9	Failure of the safety related part of control system - End Effectors	☐	☐	☒
	It is considered to have PL=d + Cat3, according to standard, which will be supported by its manufacturer's certification. It is not part of this preliminary verification			
1.10	Unexpected movements due to new start-up	☒	☐	☐
	Reset required after a safety stop The resumption of movement between cycles is due to the automatism, which is not interrupted as long as there are no security risks, such as unauthorized intrusions.			
1.11	Unexpected movements due to mode selection	☐	☐	☒
	For the conveyor system, it is irrelevant whether it operates in one mode or another, the associated safeguards are always operational, regardless of whether the movements are carried out according to the automation programme or voluntarily or individually by the operator. The operating mode of the robot is not part of this preliminary verification.			

30. PUNCH LIST

Any incomplete task or non-conformity shall be recorded on the punch list and categorized as follows:

A → Accepted

B → Rejected

C → To be rectified for Small Scale Pilot

D → To be rectified for Final Pilot

No.	Description	Responsible	Type	Complete
1	Programming and commissioning of the laser scanners to ensure: - Absence of people inside the U-shaped zone antes o durante el ciclo. - Detection of unauthorised intrusions from the open area of the U-shaped area - Detection of presence on the outside of the conveyors (if no alternative measures are taken, see points 2 and 3 of this table). EN ISO 13855 must be taken into account			
2	Attach fixed structures up to one meter in height to the external face of the conveyors, the purpose of which is to coerce the conveyor against the crossing. In this case, EN ISO 13854 must be taken into consideration in relation to the minimum distance to be respected between the mounted structure and the wall when the conveyor is in its rest position. See 1.3 of section 4.1 of this report			
3	Provide a distancing structure in accordance with EN ISO 13857, preventing access by hands and fingers to the closing area between conveyors B and C during the closing movement of C.			
4	Set the PXC driver functionalities to trigger a stop, or reversal of direction of movement, in case of possible obstacle (e.g. human body part).			
5	Functional validation of the safety functions according to EN ISO 13849-1, justifying design according to PL=d + cat 3 and performing the appropriate injection and failure tests. - Emergency stop - Shutdown by activation of the laser scanner - Reset			