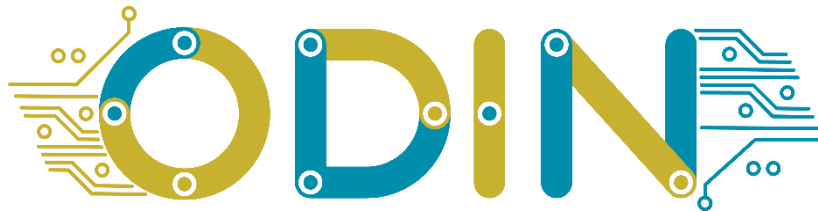


Open-Digital-Industrial and Networking pilot lines using modular components for scalable production

Grant Agreement No : 101017141
Project Acronym : ODIN
Project Start Date : 1st January, 2021
Consortium : UNIVERSITY OF PATRAS – LABORATORY FOR MANUFACTURING SYSTEMS AND AUTOMATION
FUNDACION TECNALIA RESEARCH & INNOVATION
KUNGLIGA TEKNISKA HOEGSKOLAN
TAMPEREEN KORKEAKOULUSAATIO SR
COMAU SPA
PILZ INDUSTRIE ELEKTRONIK S.L
ROBOCEPTION GMBH
VISUAL COMPONENTS OY
INTRASOFT INTERNATIONAL SA
GRUPO S21SEC GESTIÓN, S.A.
FUNDACION AIC AUTOMOTIVE INTELLIGENCE CENTER FUNDAZIOA
DGH ROBOTICA, AUTOMATIZACION Y MANTENIMIENTO INDUSTRIAL SA
PSA AUTOMOBILES S.A.
AEROTECNIC COMPOSITES SL. U.
WHIRLPOOL EMEA SPA
WHIRLPOOL MANAGEMENT EMEA SRL



Title : ODIN Industrial Component – First Version
Reference : D5.2
Availability : Public
Date : 29/12/2022
Author/s : DGH, LMS, TECNALIA, PSA, AEROTECNIC, WHEMAN

Summary:

The purpose of this document is to describe the first version of the ODIN Industrial Large-Scale pilots.

Table of Contents

LIST OF FIGURES	3
LIST OF TABLES	5
EXECUTIVE SUMMARY	6
1. INTRODUCTION.....	7
2. ODIN AUTOMOTIVE PILOT DEMONSTRATOR	8
2.1. Overview	8
2.2. Automotive demonstrator at LMS premises	8
2.2.1. Final layout VS current status of layout	9
2.2.2. Integration of Open Component with automotive initial demonstrator.....	10
2.2.3. Integration of Digital Component with automotive initial demonstrator	12
2.2.4. Integration of Networked Component with automotive initial demonstrator..	14
2.3. Automotive demonstrator at TECNALIA premises.....	15
2.3.1. Final layout VS current status of layout	15
2.3.2. Integration of Open Component with automotive initial demonstrator.....	16
2.3.3. Integration of Digital Component with automotive initial demonstrator	17
2.3.4. Integration of Networked Component with automotive initial industrial pilot	18
3. ODIN AERONAUTICS PILOT DEMONSTRATOR.....	19
3.1. Overview	19
3.2. Aeronautics demonstrator at TECNALIA premises	19
3.2.1. Final layout VS current status of layout	20
3.2.2. Integration of Open Component with Aeronautics initial demonstrator	22
3.2.3. Integration of Digital Component with Aeronautics initial demonstrator	26
3.2.4. Integration of Networked Component with Aeronautics initial demonstrator .	27
4. ODIN WHITE GOODS PILOT DEMONSTRATOR	28
4.1. Overview	28
4.2. White Goods demonstrator at LMS premises	28
4.2.1. Final layout VS current status of layout	29
4.2.2. Integration of Open Component with White Goods initial demonstrator	30
4.2.3. Integration of Digital Component with White Goods initial demonstrator	31
4.2.4. Integration of Networked Component with White Goods initial demonstrator	33
5. CONCLUSIONS.....	36
6. GLOSSARY.....	37
7. REFERENCES.....	38

LIST OF FIGURES

Figure 1: Large-scale Pilot Lines of Industrial Component – connection with other ODIN Components	7
Figure 2. Automotive pilot demonstrator overview	8
Figure 3: Automotive pilot final layout at LMS premises	9
Figure 4: Automotive pilot initial demonstrator at LMS premises	10
Figure 5: Quality inspection module identifying the state of different connectors (a,b,c) and screws (d) on the assembly as OK or NOT OK	10
Figure 6: CADMatch module identifying the motor pose	11
Figure 7: Integration of the AR application in the automotive pilot demonstrator	11
Figure 8: Design and implementation of the automotive motor gripper	12
Figure 9: Simulation of automotive pilot initial demonstrator	12
Figure 10: Automotive pilot initial demonstrator tasks modelling in AI Task Planner	13
Figure 11: Automotive pilot final demonstrator tasks modelling in AI Task Planner	13
Figure 12: Automotive pilot initial demonstrator task list in OpenFlow	14
Figure 13. OpenFlow connection with ROS action servers and required components for initial automotive pilot execution	15
Figure 14. Simulated layout of the final automotive demonstrator - Operation 2	16
Figure 15. Screwing while moving - initial automotive demonstrator	16
Figure 16. Visual servoing for screwing while moving operation	17
Figure 17. Screw while moving skill utilizing a conveyor belt	17
Figure 18. TECNALIA mobile robot screwing the motor in motion inside simulation	18
Figure 19. TECNALIA mobile robot finishes screwing and the motor proceeds to next station	18
Figure 20. a) Template-base drilling. b) Fan cowl quality inspection. c) Fan-Cowls handling and transportation	19
Figure 21. AEROTECNIC overall workshop layout	20
Figure 22. Virtual layout of the AEROTECNIC workshop: a) Drilling area. b) Verification/Inspection area	21
Figure 23. Inner part of the fan cowl used for inspection operation	21
Figure 24. Outer part of the fan cowl - templates installed for guiding the drilling operation	21
Figure 25. Aeronautics initial demonstrator for transporting operation	22
Figure 26. First version of the mast with Lidar installed on top	23
Figure 27. Refined version of the mast: more robust, better grip and cables for reducing oscillations	23
Figure 28. Drilling template detection with RC CADMatch module	24
Figure 29. Blockly based GUI for skill programming	24
Figure 30. Trajectory teaching by the operator	25
Figure 31. GUI for guiding the operator	25
Figure 32. CAD Programming user interface for CATIA	26
Figure 33. Visual Components tools modelling in aeronautics pilot	26

Figure 34. Visual Components simulation for reachability analysis	27
Figure 35: White Goods pilot demonstrator design for installation at WHEMAN premises	28
Figure 36: Final layout for the White Goods pilot demonstrator at LMS premises.....	29
Figure 37: Current setup for the White Goods pilot demonstrator at LMS premises	30
Figure 38: Results from the detection of different White Goods parts using CADMatch.....	30
Figure 39: Integration of the AR application in the white goods pilot initial demonstrator	31
Figure 40: Reconfigurable robotic tooling installed in the demonstrator: a) Wingman tool holders on the toolstand, b) rc_visard 65 camera with distancer, c) magnetic gripper, d) flexible gripper.....	31
Figure 41: White Goods pilot simulation at LMS premises	32
Figure 27: White Goods pilot final demonstrator tasks modelling in AI Task Planner.....	32
Figure 43: Exported robot trajectories through virtual commissioning	33
Figure 44: White Goods pilot demonstrator task list in OpenFlow	34
Figure 45. OpenFlow connection with ROS action servers for white goods initial demonstrator.....	35

LIST OF TABLES

Table 1. Robot resource used in Automotive pilot	8
Table 2. M24 Automotive pre-industrial pilot tasks execution.....	9
Table 3. ROS action servers for initial Automotive pilot execution.....	14
Table 4. M24 White Goods pre-industrial pilot tasks execution	28
Table 5. ROS action servers for initial White Goods pilot execution.....	34

EXECUTIVE SUMMARY

This document shows the initial version of ODIN Industrial Component focusing on the large-scale pilot lines developed under the ODIN project. More specifically, the initial status of pilot setups is presented as well as the integration [1] of ODIN hardware and software modules for each case in order to validate the performance of ODIN modules. Special efforts are given in order to have industrial pilots characterized by: industrial level robustness, industrial grade performance [12] and industrial safety.

Different technologies per pilot have been included in this document which are involved in the main components of ODIN namely the Open, Digital, Industrial and Networked Components [3].

The main objectives of ODIN Industrial Component during the ODIN lifecycle are:

- Implementation of the Automotive Pilot Line
- Implementation of the Aeronautics Pilot Line
- Implementation of the White Goods Pilot Line
- Assess the performance of these three Large-Scale Pilots

The initial results per each large-scale pilot presented in this deliverable include the following information:

- Layouts designs of the full scales pilot demonstrators in their final and existing form.
- Successful integration of the ODIN Components and individual modules.
- First testing of pilots' execution flow utilizing the aforementioned modules in the existing setups.

LEGAL DISCLAIMER

The ODIN project is co-funded by the European Union's Horizon 2020 research and innovation programme under the Grant Agreement No 101017141. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the granting authority can be held responsible for them.

1. INTRODUCTION

WP5 is centralized on ODIN Industrial Component for robust large-scale pilot lines. The main objective of this WP is the deployment of ODIN full scale demonstrators in different production sectors to serve as a token of the industrial grade performance of the ODIN production systems. ODIN Industrial Component is a full-scale instance of the pilot, integrating hardware (HW) and software (SW) modules from the Open, Digital and Industrial Components and operating under an actual production environment. The three large scale pilot demonstrators of ODIN Industrial Component will be used to exploit and disseminate ODIN results during project's progression.

This document is organized as follows:

- Section 1 provides the introduction of ODIN Industrial Component first version.
- Section 2 is focused on the description of ODIN Automotive Pilot Demonstrator.
- Section 3 is focused on description of ODIN Aeronautics Pilot Demonstrator.
- Section 4 is focused on description of ODIN White Goods Pilot Demonstrator.

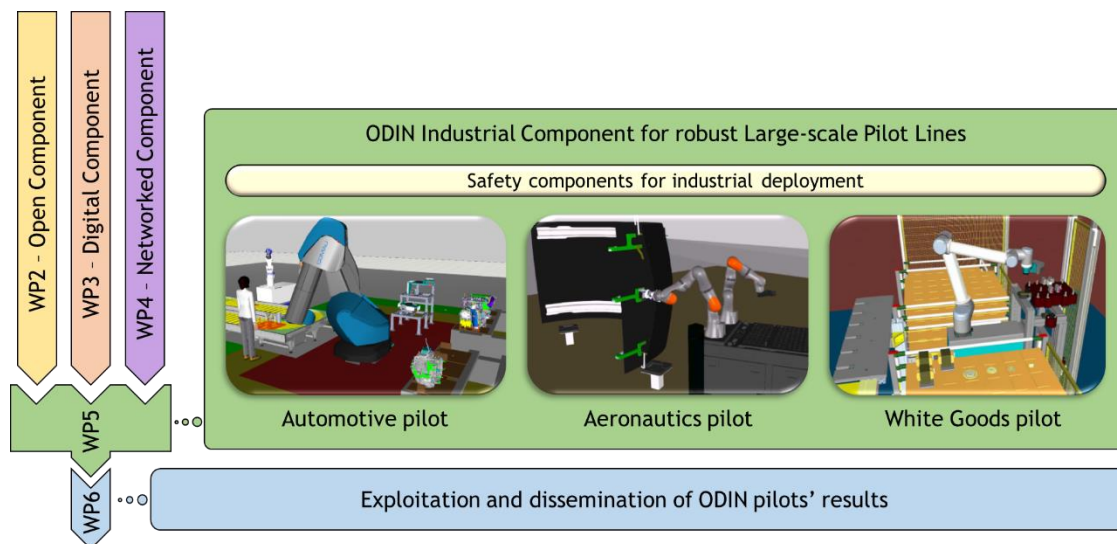


Figure 1: Large-scale Pilot Lines of Industrial Component – connection with other ODIN Components

2. ODIN AUTOMOTIVE PILOT DEMONSTRATOR

2.1. Overview

The ODIN automotive pilot final demonstrator, is designed as a solution to increase the productivity of a real industrial process at STELLANTIS premises, by utilizing key technologies developed during the project. The demonstrator consists of modules from the Open, the Digital and the Networked components of ODIN. As documented in deliverable D1.1, the final demonstrator of the automotive pilot as visualized in Figure 2 consists of three operations:

- Operation 1: Motor & gearbox assembly
- Operation 2: Additional parts assembly on the motor and gearbox assembly
- Operation 3: Quality check of installed parts on the motor and gearbox assembly

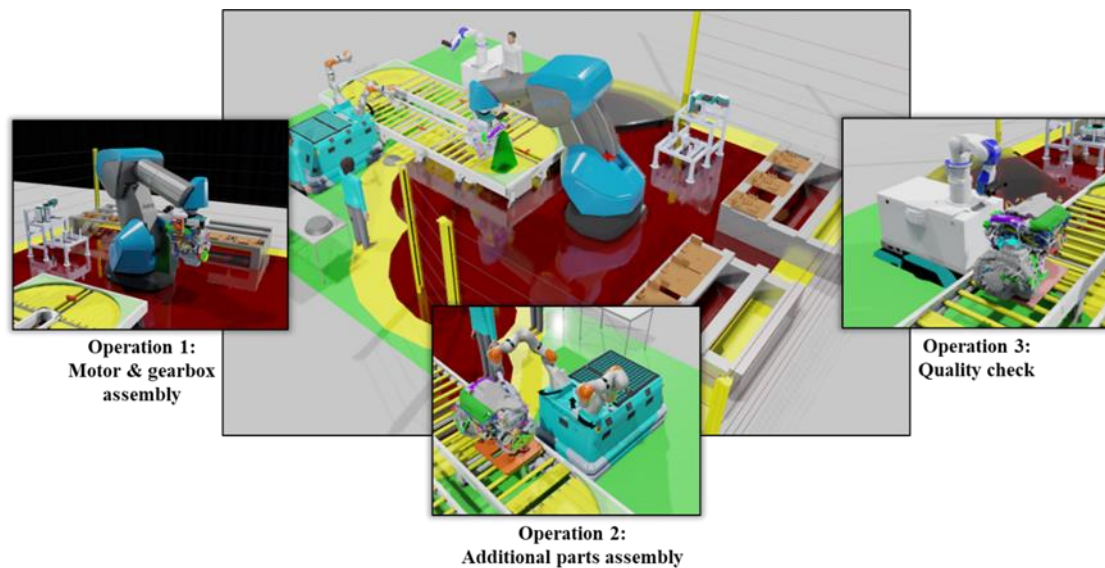


Figure 2. Automotive pilot demonstrator overview

The automotive pilot layout consists of several robot resources for the execution of the required tasks but also two human operators and several mechanical constructions for parts installation and automated tool change by the robot. The different resources used in this pilot are presented in the following table:

Table 1. Robot resource used in Automotive pilot

Resource_ID	Resource title	Operation included
1	COMAU AURA cobot [4]	Operation 1
2	Operator_1	Operation 1 / Operation 2
3	TECNALIA mobile robot	Operation 2
4	COMAU mobile robot [5, 6]	Operation 3
5	Operator_2	Operation 3

2.2. Automotive demonstrator at LMS premises

The current version of Automotive demonstrator at LMS premises on M24 is focused on the 3rd operation of the pilot namely the quality check of the installed parts on the motor and gearbox assembly. This operation consists of 2 tasks as presented in Table 2.

Table 2. M24 Automotive pre-industrial pilot tasks execution

Task_ID	Task title
1	Quality inspection
2	Digital marking / Validation of inspected results

The first task is focused on the inspection of the assembled parts using a ROBOCEPTION rc_visard 65 camera and the quality inspection algorithm as presented in submitted deliverable D2.1 of ODIN. After the execution of the quality inspection task, the operator is informed about the quality inspection result through an AR operator support application and performs corrective tasks on the motor.

2.2.1. Final layout VS current status of layout

The final layout at LMS premises is expected to include the testing ground for both operation 1 and operation 3. It includes the AURA robot with its hand guiding tool and camera, the motor and the gearbox, the grippers but also the mobile robot with its own camera. Also, an operator is required to participate in the demonstrator, to perform the connection of the gearbox to the motor collaboratively with the AURA robot. The different tasks for operation 1 will be carried on, in the same order as in the ODIN vision for the production. Finally, after operation 1 is completed, and the motor and gearbox have been assembled, the mobile robot will perform the autonomous quality inspection of the assembly, which is the base of the 3rd operation of the automotive case. In case a defect is detected, the 3rd operation continues, with the operator participating to correct the assembly as required. The final layout design at LMS premises will enable a full testing of the Operation 1 and Operation 3 technologies and procedures and is visualized in Figure 3.

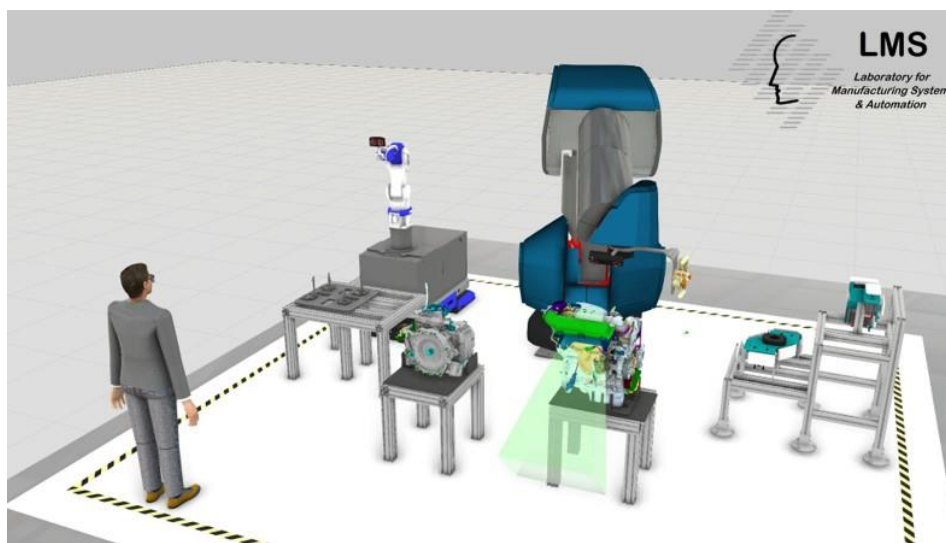


Figure 3: Automotive pilot final layout at LMS premises

Currently the ODIN layout at LMS premises is focused on the 3rd Operation. In order to realize the demonstrator of the 3rd operation at LMS premises, different actions have been successfully completed. The robotic cell is currently based on a Universal Robot UR10, installed on the top of a custom robot base. A custom flange has been designed and manufactured at LMS premises. This flange has been installed on the robot's end effector in order to mount the rc_visard 65 camera on the robot. The appropriate connectivity has also been established for the industrial camera, in order to process the results of the quality inspection module. Furthermore, a table has been assembled, to host the motor fixture and the motor which have been provided by STELLANTIS. Finally, the digital simulation analysis has been completed in order to collectively assess the camera's visibility and the robot arm's

reachability. The results of the simulation have been used to determine the exact height and position of the table in order to successfully complete the setup.



Figure 4: Automotive pilot initial demonstrator at LMS premises

2.2.2. Integration of Open Component with automotive initial demonstrator

2.2.2.1. Robotic perception for the process, the human and the environment

Following the installation of the camera's power and control units, the different digital packages of the quality inspection module have been installed on the main computer of the cell. The rc_visard 65 camera serves as the sensor for the quality inspection solution which is based on the MVTec HALCON software [7]. The quality inspection module has been trained to identify as OK or NOT OK, the different connections of parts of the motor and gearbox assembly. Such parts are screws, electrical connectors, tabs and strap holders. Indicative output from the module is visualized in Figure 5.

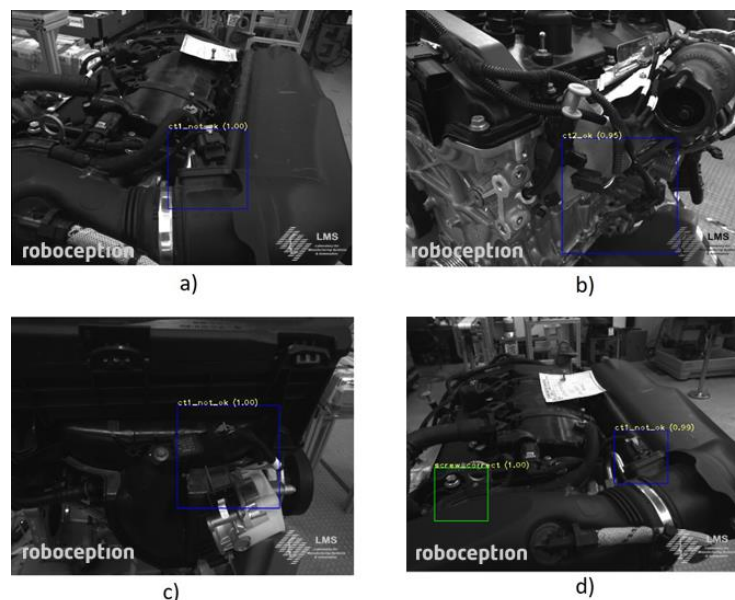


Figure 5: Quality inspection module identifying the state of different connectors (a,b,c) and screws (d) on the assembly as OK or NOT OK

The solution for detecting the position and orientation of the motor under automotive operation 1, is also integrated in the LMS demonstrator. This module is employed for the detection of the position of the motor as whole and is based on the CADMatch software by ROBOCEPTION [8]. The results of the CADMatch are expected to be utilized in order to pick the motor with the motor gripper. More specifically, the CADMatch will be used to detect the motor and inform the AURA robot on how to

approach the part, and more specifically the configuration it needs to achieve, before the gripper's actuators are switched open. The rc_visard 160 camera is the specific sensor being used by the module. This sensor has larger sensing range, than the sensor of the quality inspection module and thus it is operated from a larger distance from the part. First results of the module are visualized in Figure 6.

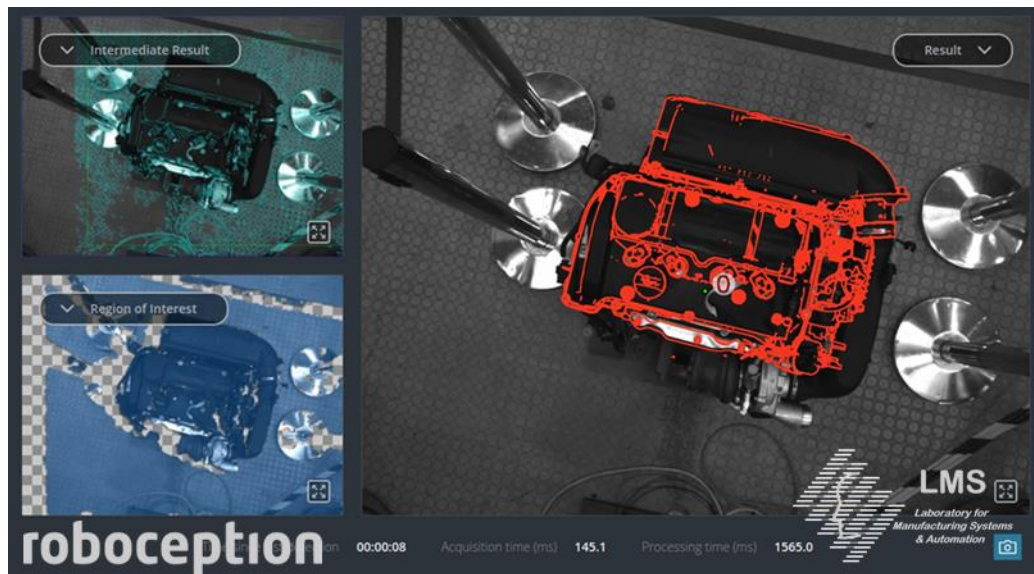


Figure 6: CADMatch module identifying the motor pose

2.2.2.2. Smart human side interfaces based on AR and wearable devices

This module has been integrated in the current demonstrator at LMS premises and more specifically has been utilized in order to inform the operator for the results of the quality inspection, during operation 3. Different virtual buttons with options and a virtual menu have been created to assist the operator to navigate when using the module. The operator is informed through a visualization of the results in the AR glasses. The result from the integration of this module is visualized in Figure 7.



Figure 7: Integration of the AR application in the automotive pilot demonstrator

2.2.2.3. Reconfigurable robot tooling

The motor gripper has been assembled and integrated in the LMS demonstrator. In order to facilitate the testing of the motor gripper, a high payload COMAU NJ370 robot has been utilized as a first step which will be substituted in the next phase of the project by the AURA robot as initially planned. An aluminium plate has been modified to serve as an interface between the robot and the motor gripper.

The gripper's pneumatic actuators have been controlled manually, in order to test the gripper on its current status. Initial tests have achieved as well as results for grasping and lifting the motor while also providing feedback for some needed design-related updates for the motor gripper, in order to better secure the quite heavy motor part.

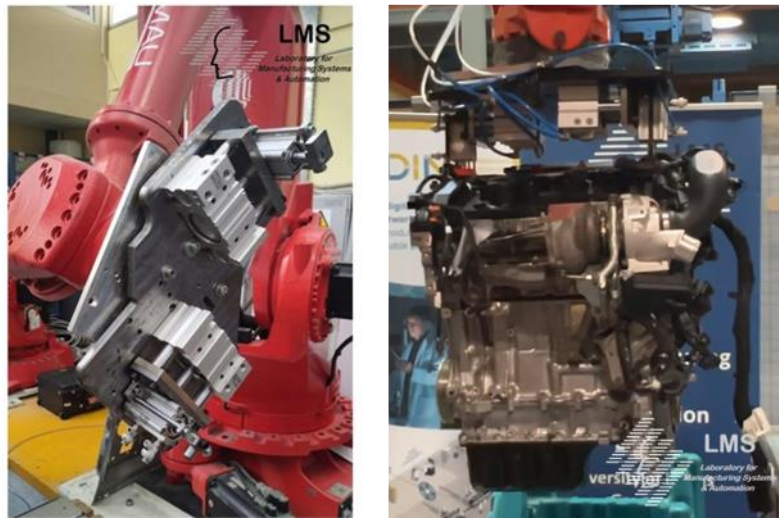


Figure 8: Design and implementation of the automotive motor gripper

2.2.3. Integration of Digital Component with automotive initial demonstrator

Until M24 of ODIN, a set of Digital Component modules have been integrated and tested in the initial pilot setup of the automotive pilot case at LMS premises with the support of individual developer partners.

2.2.3.1. Digital Simulation

The digital simulation of the Automotive pilot is focused on the assembly, screwing and quality check of a motor engine. The digital simulation has been built based on the process modelling methodology of Visual Components software. As a first step, the layout of the existing pilot setup has been inserted in the VIS software as presented in the following figure.

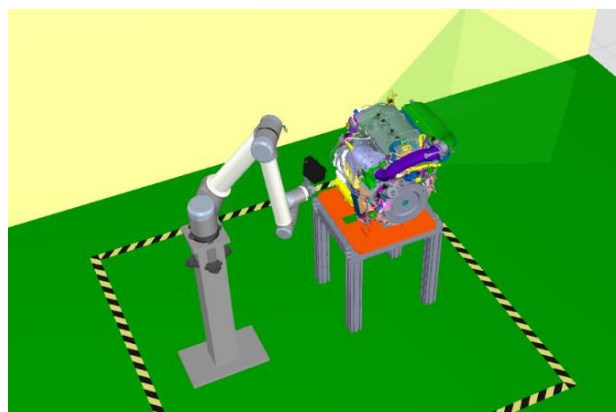


Figure 9: Simulation of automotive pilot initial demonstrator

This digital simulation will be up to date during the progression of the project with the latest robot resources and tools.

In order to validate the vision layout of this industrial pilot, another simulation has been designed by LMS focused on the target version of automotive industrial pilot at LMS. One AURA robot and the

COMAU mobile platform will be utilized for the realization of required tasks of this pilot case. The vision layout of the industrial pilot setup is visualized through the VIS software in Figure 3.

2.2.3.2. AI Task Planner

The prototype version of ODIN AI task planner has been detailly presented in deliverable D3.1. This module’s integration in automotive pilot initial setup is focused on the modelling of the resources (robots and operators) but also on the modelling of the required assembly tasks. Until M24 of the project, the tasks modelled for the AI Task Planner are focused on quality inspection of motor (operation 3 of automotive pilot). In more details, the tasks modelling is presented in the following figure.

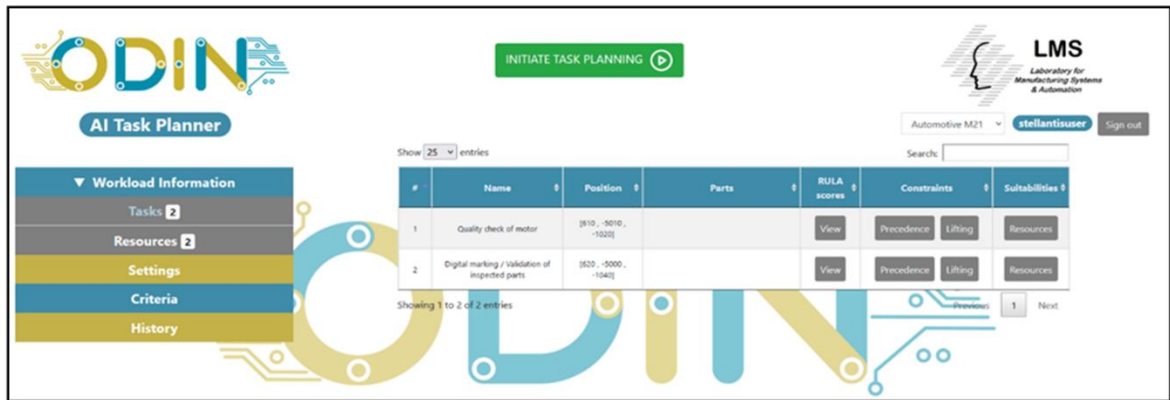


Figure 10: Automotive pilot initial demonstrator tasks modelling in AI Task Planner

The task planner algorithm is utilized in order to find the best suitable task plan alternative to assemble the selected product. The result of the task planning procedure passes to the OpenFlow in order to assign and monitor each task’s execution.

Thanks to STELLANTIS input, LMS was able to summarize all the required tasks for the automotive pilot and make a list with important information per task (working area in which each tasks takes place in, the available resources able to execute each task and weight etc.). Using this information, LMS modelled all required assembly tasks and added them in the AI task planner in order to validate them in the final version of the industrial pilot until M36.

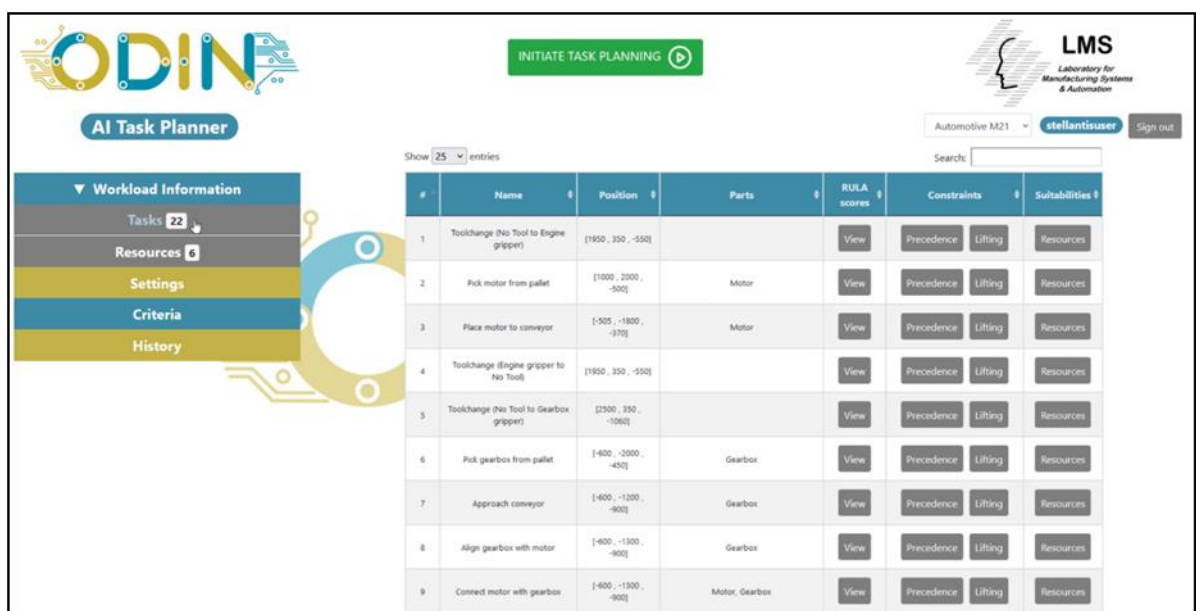


Figure 11: Automotive pilot final demonstrator tasks modelling in AI Task Planner

2.2.4. Integration of Networked Component with automotive initial demonstrator

2.2.4.1. OpenFlow

The initial version of OpenFlow has been integrated and validated in the initial Automotive industrial pilot setup at LMS premises following the ODIN OpenFlow architecture (Figure 12). The OpenFlow prototype is described in D4.1 and the validation of the integration is described in D4.2. The latest version of OpenFlow has been installed in a high-performance PC at LMS premises which is connected in the same network with the UR10 cobot controller and Hololens AR glasses.



Figure 12: Automotive pilot initial demonstrator task list in OpenFlow

The OpenFlow uses the result of the AI task planner in order to assign assembly tasks to the available components and monitor their successful execution. The correct connection and usage of OpenFlow is based on a set of ROS action servers available through the local network of the pilot waiting for Action goals to be sent from the OpenFlow.

As documented in section 2.2.1, the current version of ODIN layout at LMS premises is focused on the quality inspection of motor parts assembled on the motor. In this case, three ROS action servers are used by the OpenFlow for the execution of the required actions (Table 3).

Table 3. ROS action servers for initial Automotive pilot execution

ROS Action Servers	Description
Move Joint Action Server	Action server for the planning and execution of robot motions using Joint space goals.
Execute Human Task Action Server	Action server for the connection of AR operator support application with the OpenFlow.
Quality Inspection Action Server	Action server for the execution of the quality inspection algorithm.

The connection of OpenFlow with the aforementioned ROS Action servers and the required ROS Controllers and hardware / software components is visualized in Figure 13.

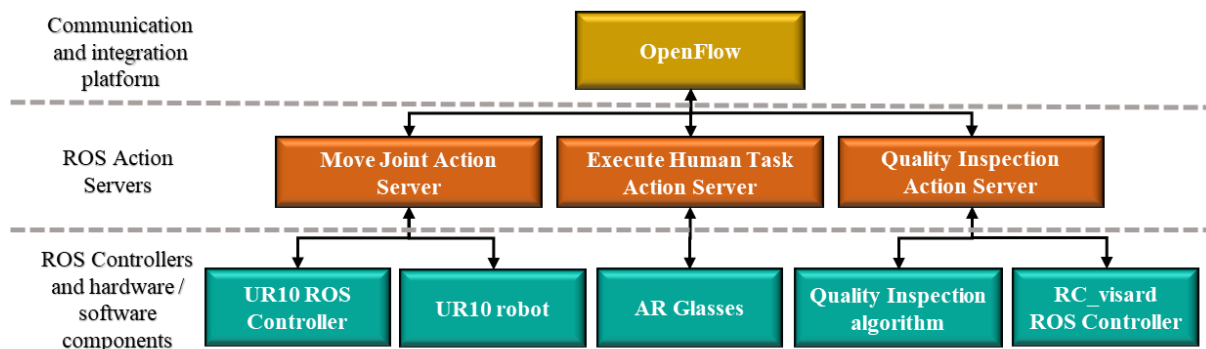


Figure 13. OpenFlow connection with ROS action servers and required components for initial automotive pilot execution

2.3. Automotive demonstrator at TECNALIA premises

The operation 2 of the automotive pilot case consists of performing a screwing while moving operation. After the connection of the gearbox with the motor performed under operation 1, additional parts should be installed/screwed in the motor & gearbox assembly. The whole procedure will be in motion in a conveyor belt, and the mobile manipulator will screw while moving following the conveyor.

The current state of operation 2 can be subdivided in the following steps:

1. TECNALIA mobile robot approaches to the initial position of the conveyor belt.
2. When the motor passes in front of the robot, the mobile platform starts tracking and following it along the conveyor.
3. Then, the screwing while moving operation starts. This step allows motor and gearbox to be assembled each other and even the assembly of additional parts.
4. When the screwing operation is finished, the TECNALIA mobile robot goes away from the conveyor belt, leaving the motor moving to the next station.

2.3.1. Final layout VS current status of layout

The layout designed in WP1 (Figure 14) consists on a conveyor belt that allows the motor + gearbox moves along it for performing the operations presented in the overview (Section 2.1). As introduced in this section, in the following paragraphs the focus is set on the operation 2 of automotive pilot.

Taking as reference the layout designed in WP1, until M24 at TECNALIA premises, an initial demonstrator has been implemented for integrating the developed ODIN technologies and preparing the required resources for a further final layout integration. The current demonstrator is composed by a small conveyor which is used for transporting a mock-up of the motor and gearbox (Figure 15). Based on this setup, the mobile manipulator uses visual servoing techniques for accomplishing the screwing while moving operation.

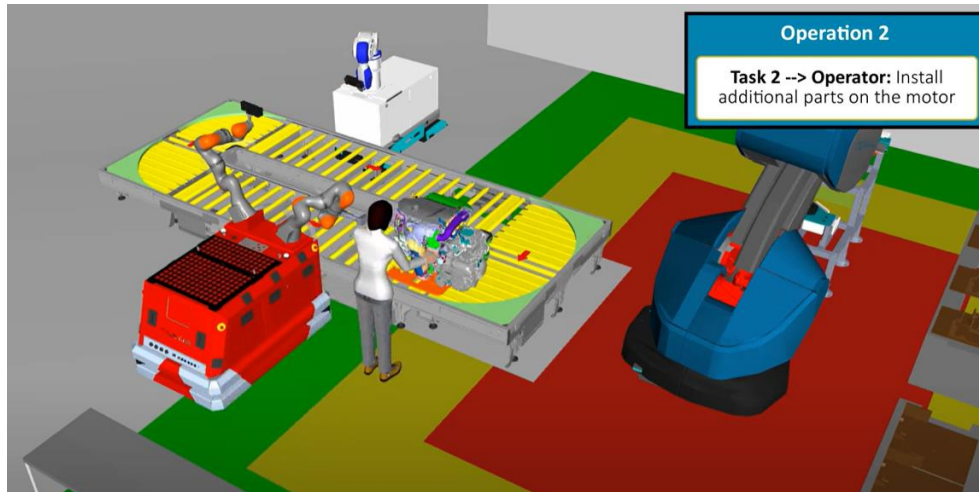


Figure 14. Simulated layout of the final automotive demonstrator - Operation 2



Figure 15. Screwing while moving - initial automotive demonstrator

2.3.2. Integration of Open Component with automotive initial demonstrator

Until the end of M24, the automotive pilot operation 2 presents advances on the screw while moving skill through visual servoing. However, in the following phases, additional Open Component modules will be integrated, namely the 3D navigation and user-friendly robot programming interfaces.

2.3.2.1. Screw while moving skill through visual servoing

Regarding the screw while moving skill, the following features have been developed and integrated in the automotive pilot until M24:

- Multitool controller
- Basic twist controller
- Cartesian twist controller
- Marker based visual servoing app

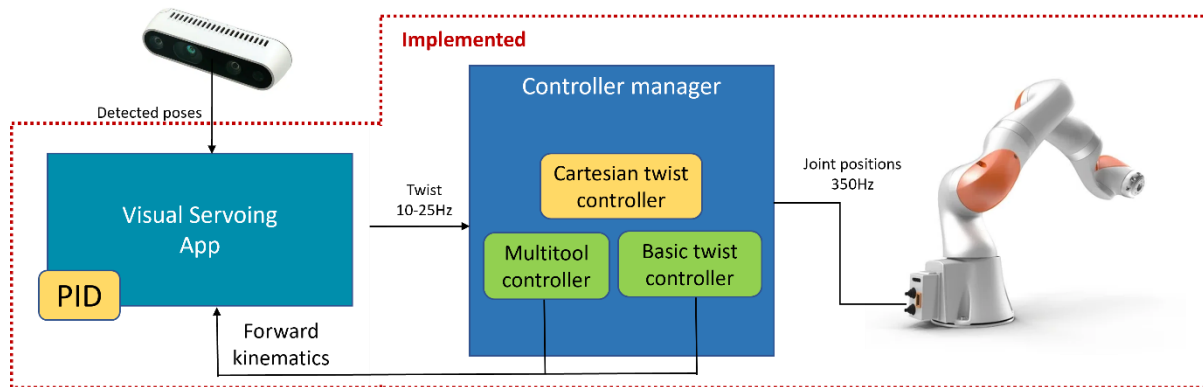


Figure 16. Visual servoing for screwing while moving operation

With these features integrated and working at the TECNALIA's mobile robot, the first prototype of marker tracking shown in the 1st Review Meeting has been integrated in more realistic demonstrator. In the updated pilot the platform works completely autonomous, following a marker with a frontal camera for going along the conveyor, and tracking the motor (which has an additional marker) with the robot arm. This set-up mimics more accurately the final layout of the industrial pilot. In the Figure 17 the first results of the demonstrator can be seen.



Figure 17. Screw while moving skill utilizing a conveyor belt

2.3.3. Integration of Digital Component with automotive initial demonstrator

Until the end of M24, the digital simulation of the automotive pilot has been integrated including also the operation 2.

2.3.3.1. Digital simulation

Thanks to the Visual Components software the desired models for automotive pilot operation 2 have been included. The simulation provides lot of details at early stages which allow understanding the required steps for accomplishing the operation. Besides allows designing and planning the required hardware and software.

In Figure 18, it is visualized how the TECNALIA mobile robot starts following the motor at the conveyor belt. Then, the screwing operations are performed, and when finishes, the robot goes away and leaves the motor in the conveyor moving to the next station (Figure 19).

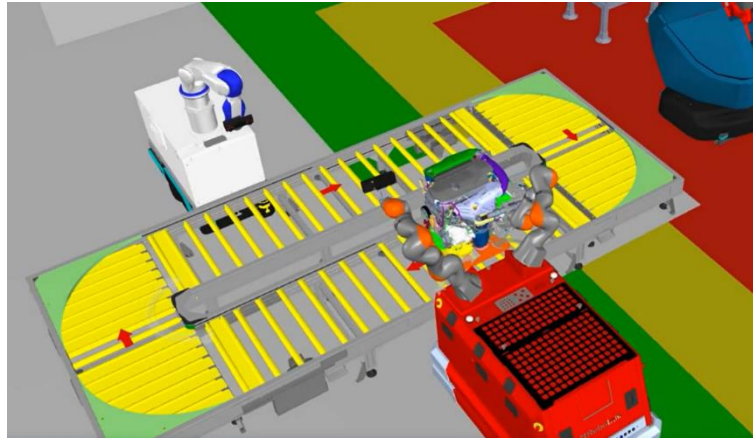


Figure 18. TECNALIA mobile robot screwing the motor in motion inside simulation

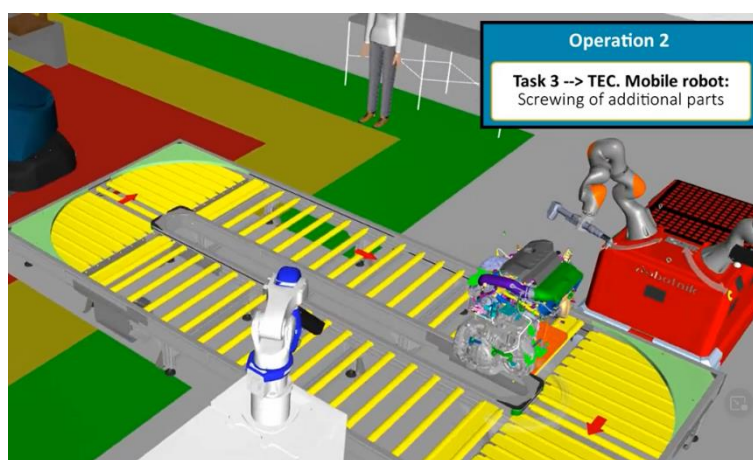


Figure 19. TECNALIA mobile robot finishes screwing and the motor proceeds to next station

2.3.4. Integration of Networked Component with automotive initial industrial pilot

Until the end of M24, the OpenFlow under the Networked Component for the automotive operation 2 is in the process of integration. Currently, this integration is in a preliminary phase and the required interfaces have been defined and refined. In the following phases, the integration will be tested in a simulation environment.

2.3.4.1. OpenFlow integration

Up to M24, work has been done on integrating the skill engine into OpenFlow through ROS interfaces. The TECNALIA's user friendly robot programming interfaces are developed on top of TECNALIA's robot programming framework. Skills for easy programming are one of the modules of the framework. There is an Execution Engine which manages the available resources and the skills that can be executed. The Execution Engine implements an action server, which will be available to execute the skills orchestrated and dispatched by OpenFlow. Currently for operation 2 of the automotive pilot the following actions have been defined:

- Navigation
- Docking
- Screw while moving

OpenFlow can request the accomplishment of the actions presented above, performing the required skills for Automotive Pilot – Operation 2.

3. ODIN AERONAUTICS PILOT DEMONSTRATOR

3.1. Overview

The ODIN project aims to automate 3 manual processes in the aeronautics pilot:

- **Template-based drilling** of holes on the two parts of the fan-cowl, for the assembly components.
- **Fan-Cowls handling and transportation** of the parts between different workstations.
- **Inspection** of the parts, for several purposes (detection of presence / absence of components / features, checking the right assembly of components, detection of defects, etc.)

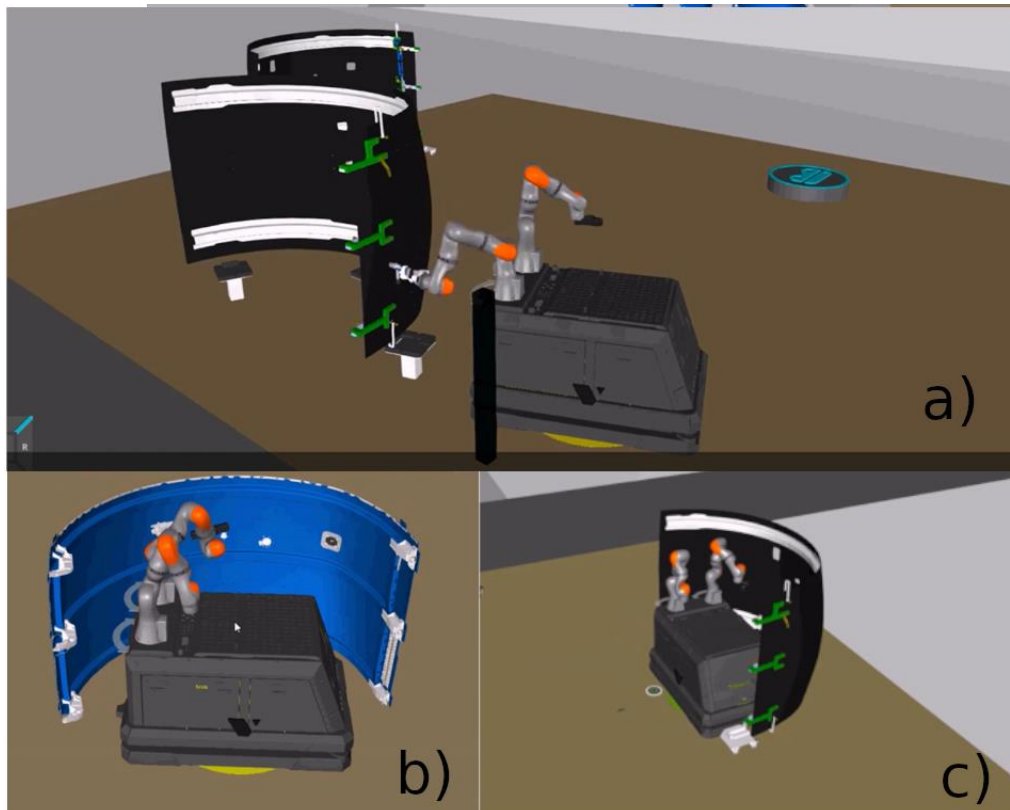


Figure 20. a) Template-base drilling. b) Fan cowl quality inspection. c) Fan-Cowls handling and transportation

3.2. Aeronautics demonstrator at TECNALIA premises

At TECNALIA premises a pilot cell has been constructed for demonstrating the three operations: template-based drilling, fan-cowl transportation and inspection. TECNALIA has on its disposal two fan-cowls ceded by AEROTECNIC.

On the one hand, one of them is being used for template-based drilling and inspection. The part is equipped with templates for guiding the drilling process. Next to the part a warehouse of tools has been installed, which improve the reconfigurability of the pilot allowing different kind of drilling tools. On the inside (concave face), some of the elements (sent by AEROTECNIC) have been installed. These elements will be scanned once for creating a reference model, and afterwards some of them will be slightly moved or removed for demonstrating the inspection procedure. On the other hand, the additional fan-cowl is being used for demonstrating transportation operation, the fan-cowl will be located on top of a wheeled cart with a clamping device (designed and validated by AEROTECNINC and PILZ) for being able to attach to the TECNALIA mobile robot.

3.2.1. Final layout VS current status of layout

The layout designed in WP1 (Figure 21, Figure 22) consists of two main areas (drilling area and verification/inspection area) and different locations where fan cowls are transported.

Taking as reference the designed layout in WP1, until M24 at TECNALIA premises, an initial demonstrator for aeronautics pilot has been implemented for demonstrating, at this stage of the project, drilling and inspection operations.

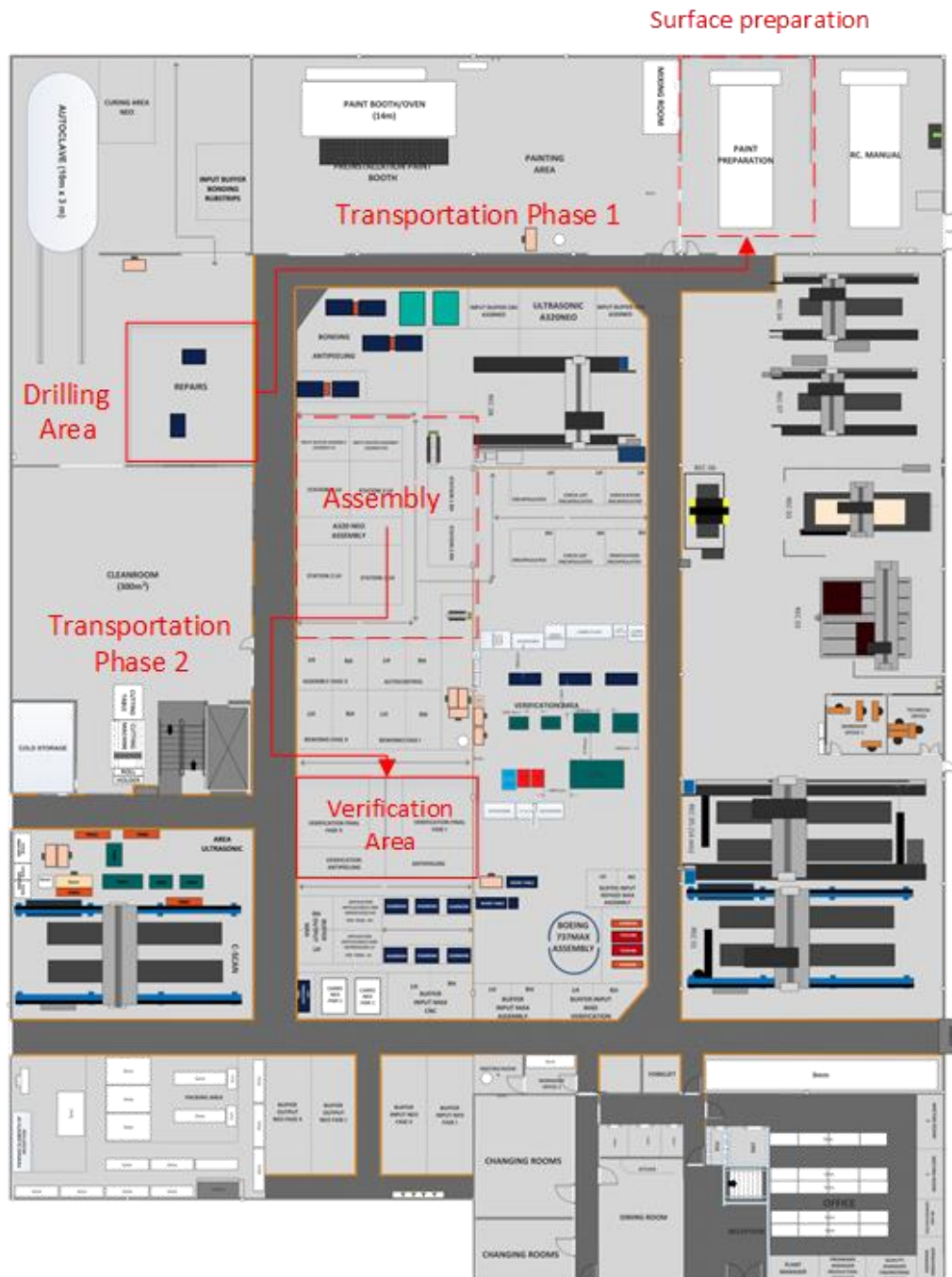


Figure 21. AEROTECNIC overall workshop layout

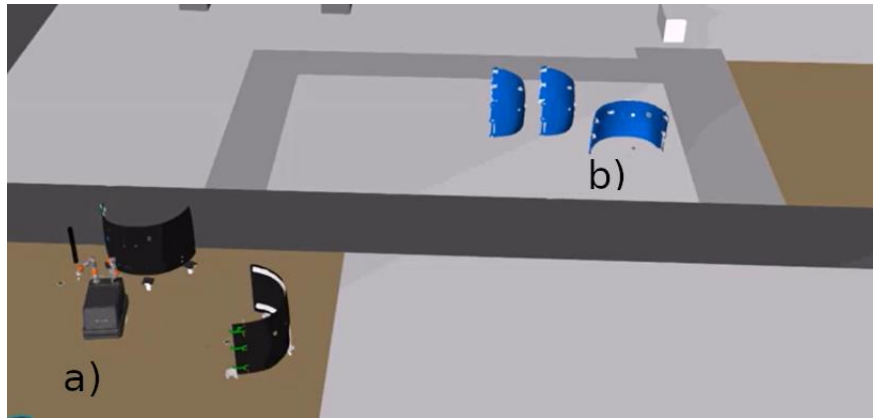


Figure 22. Virtual layout of the AEROTECNIC workshop: a) Drilling area. b) Verification/Inspection area

The current status of the aeronautics pilot demonstrator can be seen in the Figure 23 and Figure 24. As mentioned above, one of the available fan cowls is used for drilling and inspecting operations. The inner part of the fan cowl is used for inspection purposes, since the equipped parts are located there. In the outer part has been installed a drilling template for performing drilling operations.



Figure 23. Inner part of the fan cowl used for inspection operation



Figure 24. Outer part of the fan cowl - templates installed for guiding the drilling operation

Even though at this stage the transportation operation is not yet ready for a completed demonstration, some tests has been performed with the other fan cowl regarding the mounting of the Lidar sensor on the TECNALIA mobile robot (Figure 25).



Figure 25. Aeronautics initial demonstrator for transporting operation

3.2.2. Integration of Open Component with Aeronautics initial demonstrator

Until the end of M24, the initial aeronautics demonstrator integrates the following Open Component modules: 3D navigation and localization for mobile manipulators, robotic perception for the environment, process, and human, and user friendly robot programming interfaces.

3.2.2.1. 3D Navigation and localization for mobile manipulators.

Until M24, 3D navigation and localization technologies have been tested and implemented in different phases. In the first phase a testing mobile platform was used, this platform is equipped with a SICK safety laser (S3000) + a Lidar (Robosense RS-LiDAR-16). A selected set of 3D navigation and localization packages were tested with this platform for validating the technology. In the second phase, the Odin mobile manipulator was used, which is equipped with 2 SICK safety lasers (microScan3) + a LIDAR (Ouster OS1), which is mounted on a mast to allow an unobstructed field of view when the aeronautical pilot case fan cowl transport operation is being performed. In the first version (Figure 26), the mast oscillates when the robot moves (and also when the internal parts of the Lidar turns), but it was enough for validating the field of view of the Lidar. In a refined version (Figure 27) a most robust mast has been designed, with a better grip devices and cables for reducing the oscillations. The performed tests have returned better results and can be considered as final design.



Figure 26. First version of the mast with Lidar installed on top



Figure 27. Refined version of the mast: more robust, better grip and cables for reducing oscillations

3.2.2.2. Robotic perception for the environment, process and human

At this stage, the drilling template detection have been developed integrating ROBOCEPTION CADMatch module. Thanks to it, the drilling template pose, and consequently, all the drill poses can be detected with the rc_visard sensor. Figure 28 presents the obtained results of the detection.



Figure 28. Drilling template detection with RC CADMatch module

3.2.2.3. User friendly robot programming interfaces

Under the premise of user-friendly robot programming interfaces, different technologies and software modules provides various GUI and different approaches for supporting the goal of an easier robot programming concept. D2.2 present in detail these modules, but in the following sub-sections, how they are integrated in the initial industrial pilot is presented.

Advanced behaviour management

For generating robotic applications in an easy way, the appropriate compromise between simplicity and functionality must be achieved. On the one hand, intuitive GUI are required, and on the other hand, an advanced enough backend which must be able to feed the GUI with the required information is also imperative.

Blockly based GUI combined with meta-information associated to each skill improves the flexibility while reducing the complexity of new robot application programming. Figure 29 presents an example for aeronautics drilling operation.

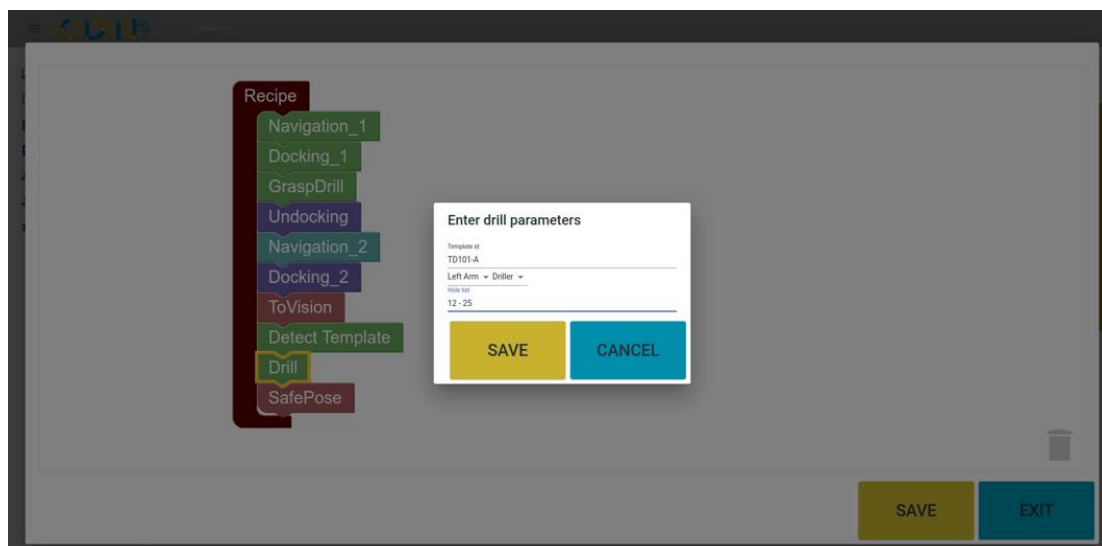


Figure 29. Blockly based GUI for skill programming

On-site interactive skill programming

Some complex operations cannot be easily implemented using skill-based programming approaches. For filling this gap On-site Interactive Skill Programming system is being developed in ODIN project. Some examples could be, precise movements in narrow spaces, agile pose recording, big part manipulation, etc. This approach enhances a trajectory teaching software with skill metainfo and skill templates for making easier teaching process (Figure 30, Figure 31).



Figure 30. Trajectory teaching by the operator

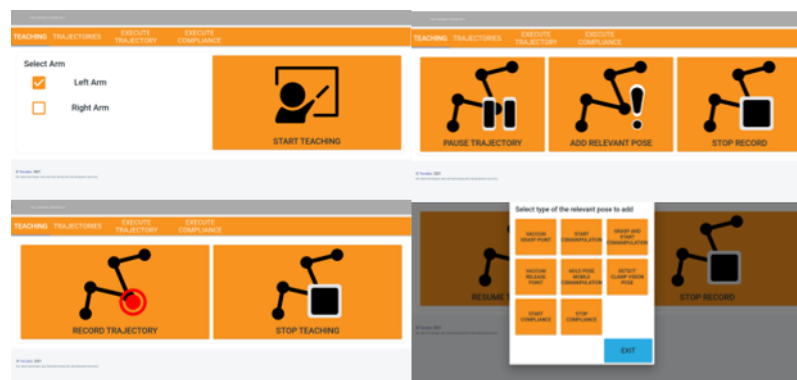


Figure 31. GUI for guiding the operator

CAD Programming

Regarding the skills which require CAD information, they can benefit from the updates that are being developed under ODIN project. The main development has been centered on allowing a dynamic GUI that can represent new skill buttons based on XML configuration files. Besides a better integration with ROS/Gazebo is being developed with the possibility of exporting CATIA scenes into a gazebo compatible world file (Figure 32).

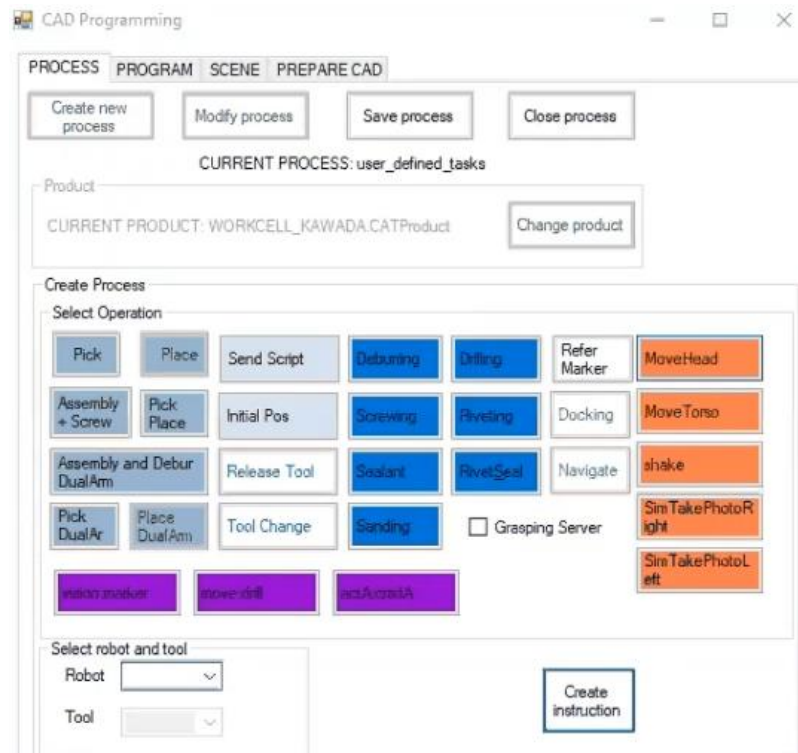


Figure 32. CAD Programming user interface for CATIA

3.2.3. Integration of Digital Component with Aeronautics initial demonstrator

Until the end of M24, a digital simulation of the aeronautics pilot has been integrated as part of the Digital Component.

3.2.3.1. Digital simulation

Thanks to Visual Components software the desired cell for aeronautics pilot has been modelled. The simulation provides lot of details at early stages which allow understanding the required steps for accomplishing the operation. Besides allows designing and planning the required hardware and software. It is remarkable how Visual Components has been providing the required tools for performing a reachability analysis in order to determine the appropriate relative position of the TECNALIA mobile robot with respect of the fan cowl for drilling operation (Figure 33, Figure 34).

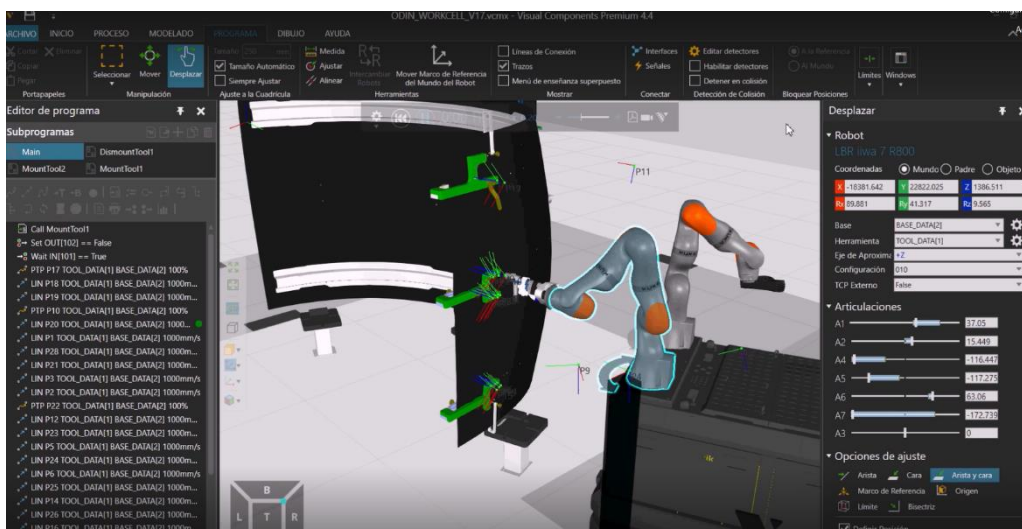


Figure 33. Visual Components tools modelling in aeronautics pilot

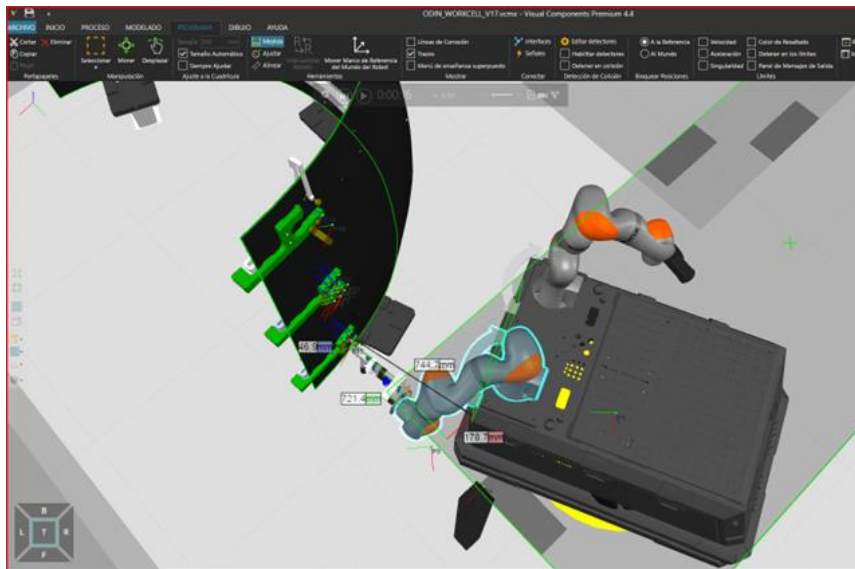


Figure 34. Visual Components simulation for reachability analysis

3.2.4. Integration of Networked Component with Aeronautics initial demonstrator

3.2.4.1. OpenFlow integration

Similarly, as in the automotive pilot case (Section 2.3.4.1), up to M24, work has been done on integrating the skill engine into OpenFlow through ROS interfaces. In the core modules of the Skill Engine, an action server will be available for executing the available skills, and on the other side they are orchestrated and dispatched by OpenFlow. Currently, for template-based drilling, transportation and inspection operations of the aeronautic pilot the following actions have been defined:

- Navigation
- Docking
- Drilling
- Transportation
- Inspection

4. ODIN WHITE GOODS PILOT DEMONSTRATOR

4.1. Overview

The white goods pilot is designed to demonstrate the functionality of key ODIN technologies and modules in the white goods industrial sector. More specifically the pilot aims to provide solutions to enhance the human robot collaboration, for reasons regarding the productivity and safety. The layout of the pilot is based on an existing industrial workstation at WHEMAN premises. The existing workstation has been developed for the assembly of electrical ovens, with the operator performing the installation of transformers on the final products, while the robot is feeding transformers to the operator, from the logistics carts. The ODIN vision is to improve the flexibility of the workstation, in terms of manipulating different white goods parts (big, medium, small cooktops, knobs and transformers), while also achieving seamless HRC and safety standards.

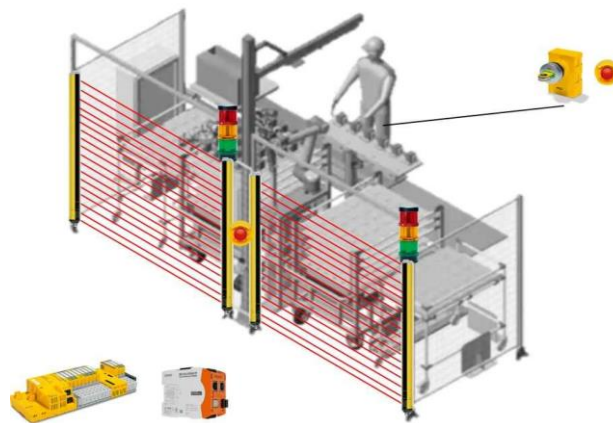


Figure 35: White Goods pilot demonstrator design for installation at WHEMAN premises

The white goods pilot layout consists of one UR10 cobot and one operator for the execution of the required assembly tasks. Additionally, several mechanical constructions for parts installation and automated tool change by the robot are included in the layout.

4.2. White Goods demonstrator at LMS premises

All the required assembly tasks are executed in the initial version of the white goods demonstrator at LMS premises on M24 for the assembly of one oven and one gas cooktop burner. In more details, the executed tasks are presented in Table 4.

Table 4. M24 White Goods pre-industrial pilot tasks execution

Task_ID	Task title
1	Toolchange (From no_tool to magnetic gripper)
2	Pick transformer from the cart
3	Place transformer on the assembly table
4	Install transformer in “microwave”
5	Pick small cooktops from the cart
6	Provide small cooktops to operator
7	Install small cooktop on the cooktop burner
8	Pick medium cooktops from the cart
9	Provide medium cooktops to operator

Task_ID	Task title
10	Install medium cooktop on the cooktop burner
11	Pick big cooktops from the cart
12	Provide big cooktops to operator
13	Install big cooktop on the cooktop burner
14	Toolchange (From magnetic gripper to no_tool)
15	Toolchange (From no_tool to flexible gripper)
16	Pick knob from the cart
17	Provide knob to operator
18	Install knob on the cooktop burner
19	Toolchange (From flexible gripper to no_tool)
20	Toolchange (From no_tool to vacuum gripper)
21	Pick cardboard from the transformer cart
22	Place cardboard on the spare cart
23	Pick separator from the transformer cart
24	Place separator on the spare cart
25	Toolchange (From vacuum gripper to no_tool)

4.2.1. Final layout VS current status of layout

The final layout at LMS premises is designed to provide the ability to test all the technologies involved in the project's vision for the white goods workstation/production. The magnetic, flexible and vacuum grippers will be hosted in a custom and reconfigurable toolstation and the tool changing process will be achieved autonomously by using the Wingman tool changer system. An rc_visard 65 camera will be used to identify the different parts and locate their position on a table's surface. The included parts are transformers, knobs, big, medium and small cooktops but also cardboards. The UR10 robot will then be utilized, using the versatile grippers to manipulate a variety of different parts, according to a schedule provided by the task planning module of ODIN Digital Component. The final layout comprises of a robotic manipulator area and a human operator area. The robotic manipulator area can be seen as the WHEMAN workstation part projection area and consists of the UR10 robot, the toolstation and the grippers, but also the kitting table and the table for placing the cardboards. The human operator can be seen as the WHEMAN workstation assembly area and includes the part projection shelf and the table for the assembly. The final layout design is visualized in Figure 36.

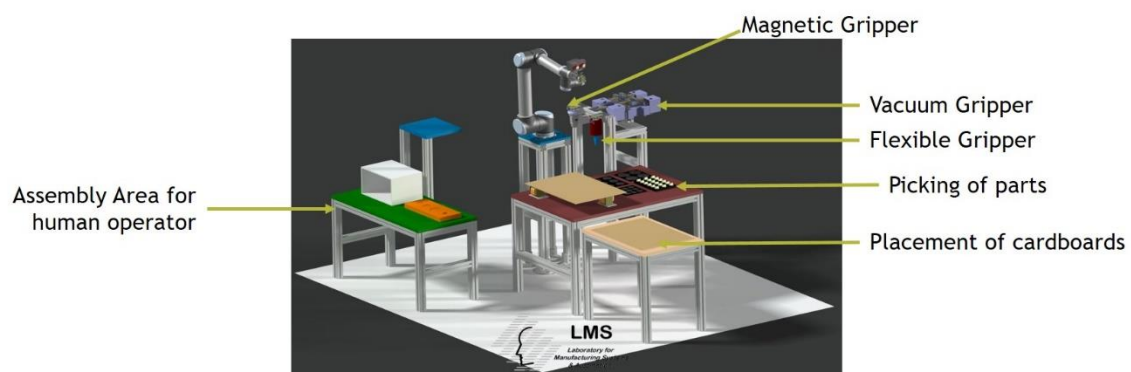


Figure 36: Final layout for the White Goods pilot demonstrator at LMS premises

Currently the setup at LMS premises includes the kitting table, the assembly shelf and the UR10 robot and its static base. The magnetic and the flexible gripper as well as the Wingman tool changer system have been included, while the rc_visard 65 camera has also been installed on the robot. The current version of the layout is visualized in Figure 37.

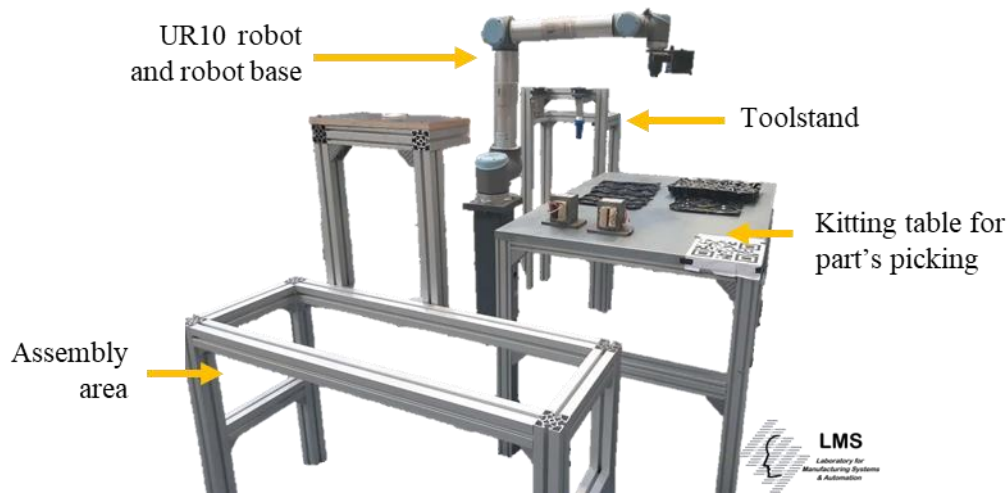


Figure 37: Current setup for the White Goods pilot demonstrator at LMS premises

4.2.2. Integration of Open Component with White Goods initial demonstrator

4.2.2.1. Robotic perception for the process, the human and the environment

This module includes two software solutions the CADMatch and the SilhouetteMatch [9], regarding the detection of the different White Goods parts. Both these modules have been integrated in the LMS demonstrator to detect the white goods parts and estimate their respective position on the kitting table. The results of the CADMatch are expected to be utilized in order to pick the parts with the magnetic and the flexible grippers. The CADMatch detects the parts and informs the UR10 robot about the configuration it needs to achieve, before the grippers are activated to grasp the parts. The rc_visard 65 camera is the specific sensor that is used to operate this module in the White Goods demonstrator. Results from the detection of the parts are visualized in Figure 38.

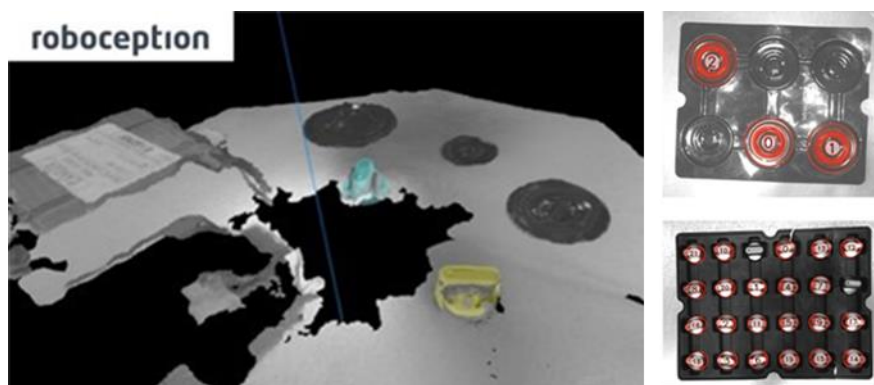


Figure 38: Results from the detection of different White Goods parts using CADMatch

4.2.2.2. Smart human side interfaces based on AR and wearable devices

This module has been integrated in the demonstrator at LMS premises. Information and controls related to the tasks assigned operator and the robot are transferred to the operator. Different virtual buttons with options and a virtual menu have been created to assist the operator to navigate when using the module. The operator is informed through a visualization of the results in the AR glasses, for the assembly

instructions and for the use of the interactive robot tool. The result from the integration of this module is visualized in Figure 39.

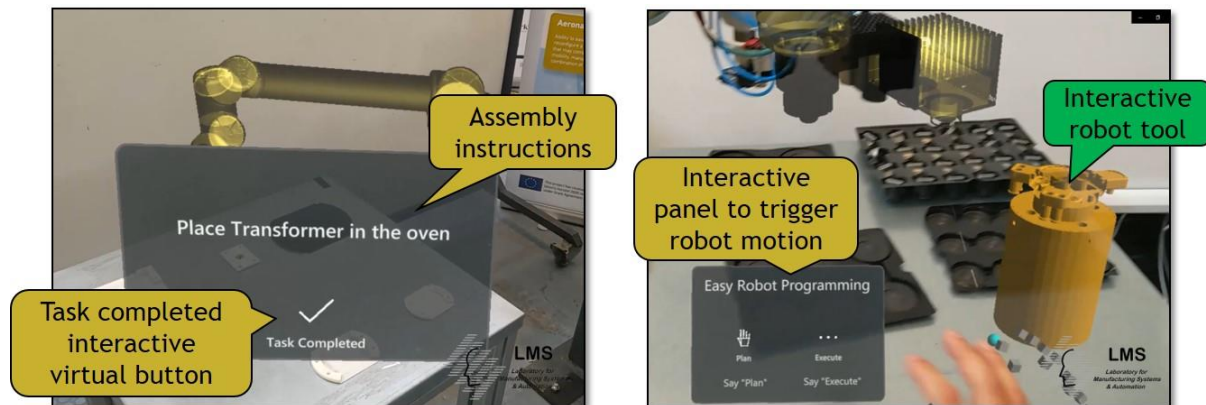


Figure 39: Integration of the AR application in the white goods pilot initial demonstrator

4.2.2.3. Reconfigurable robot tooling

The White Goods case grippers have been documented in D2.1. Currently the magnetic gripper, and the flexible gripper have been integrated into the initial demonstrator. The automatic tool changing process is achieved with the Wingman robotic tool changing system [10], which has been also integrated. More specifically, custom flanges for each gripper have been manufactured at LMS premises to connect the tools to the Wingman toolchanger system. Also, the toolstand has been assembled and integrated to the demonstrator, in order to host the Wingman tool holder parts, and the grippers. The reconfigurable vacuum gripper is expected to be integrated, as the next step regarding the robotic tooling. The installed robotic tooling is visualized in Figure 40.



Figure 40: Reconfigurable robotic tooling installed in the demonstrator: a) Wingman tool holders on the toolstand, b) rc_visard 65 camera with distancer, c) magnetic gripper, d) flexible gripper

4.2.3. Integration of Digital Component with White Goods initial demonstrator

A set of Digital Component modules have been integrated and tested in the initial pilot setup of the White Goods use case at LMS premises by LMS with the support of individual developer partners.

4.2.3.1. Digital Simulation

The digital simulation of the White Goods pilot targets the assembly of oven and cooktop burners in a common workstation. The digital simulation has been built following the procedure as the Automotive pilot using the Visual Components software. The first step was the designing of White Goods pilot initial layout and its insertion in the VIS software as visualized below.

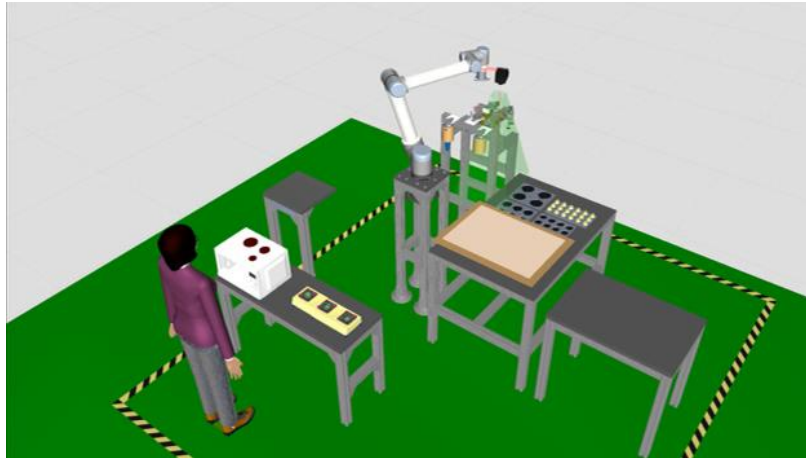


Figure 41: White Goods pilot simulation at LMS premises

The White Goods digital simulation will be up to date during the progression of the project with the latest robot resources and tools.

4.2.3.2. AI Task Planner

This module's integration in White Goods pilot initial setup follows the same approach with the Automotive pilot. As first step, its integration is focused on the modelling of the resources and the required assembly tasks. Up to M24 of the project, all tasks of White Goods use case have been modelled and added in the AI Task Planner. In more details, the modelled tasks are presented in the following figure.

#	Name	Position	Parts	OCRA scores	Constraints	Suitabilities
1	Get parallel gripper	[0, 0, 0]		View	Precedence, Lifting	Resources
2	Pick knob from the kitting table	[0, 0, 0]		View	Precedence, Lifting	Resources
3	Place knob to the assembly table	[0, 0, 0]		View	Precedence, Lifting	Resources
4	Install knob on the gas cooktop	[0, 0, 0]		View	Precedence, Lifting	Resources
5	Release parallel gripper	[0, 0, 0]		View	Precedence, Lifting	Resources
6	Get magnetic gripper	[0, 0, 0]		View	Precedence, Lifting	Resources
7	Pick transformer from the kitting table	[0, 0, 0]		View	Precedence, Lifting	Resources
8	Place transformer on the assembly table	[0, 0, 0]		View	Precedence, Lifting	Resources

Figure 42: White Goods pilot final demonstrator tasks modelling in AI Task Planner

The task planner algorithm is used to find the best suitable task plan alternative for the assembly of cooktop burner and oven products. The result of the task planning procedure passes to the OpenFlow in order to assign and monitor each task's execution.

4.2.3.3. Virtual Commissioning

The initial version of ODIN virtual commissioning solution has been integrated in the White Goods pilot in order to proof its validity. Using the virtual commissioning framework of VIS, LMS was able to test the accuracy of robot trajectories sent from VIS software to the real controller of UR10 cobot for execution. Using a custom plugin of the digital simulation called “PostProcessor”, a URscript was able to be automatically generated by the Visual Component and be imported in the cobot’s controller for the execution of simulated trajectories from the physical robot. Until the end of the project, this process will become fully automated by directly connecting VIS simulation with the physical robot for transferring data from the digital simulation to the cobot controller.

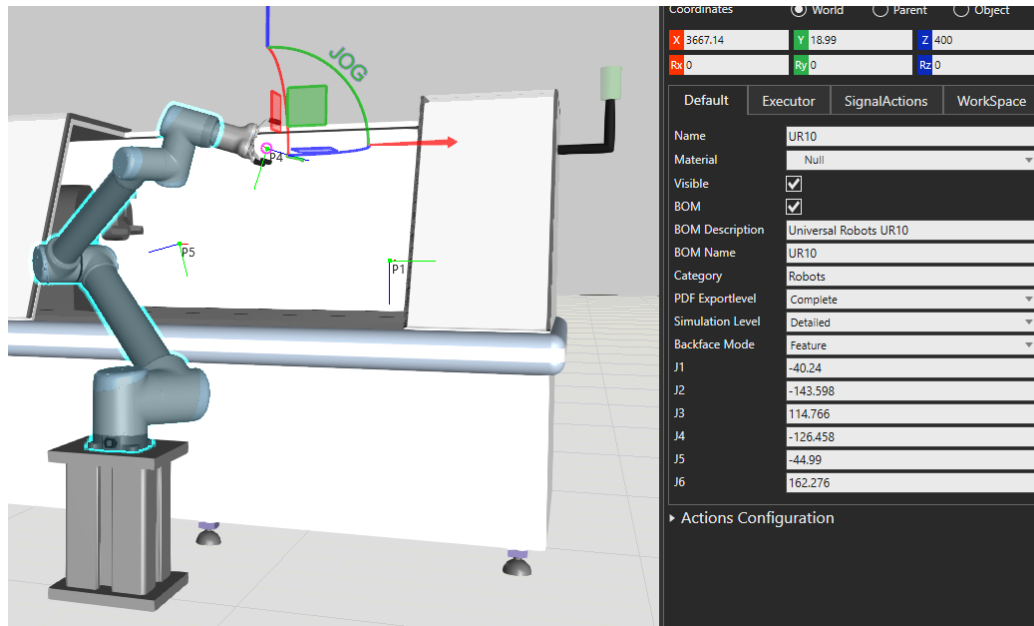


Figure 43: Exported robot trajectories through virtual commissioning

4.2.4. Integration of Networked Component with White Goods initial demonstrator

4.2.4.1. OpenFlow

The prototype version of OpenFlow has been integrated in the initial White Goods industrial pilot at LMS premises according to the ODIN OpenFlow architecture (Figure 44). The OpenFlow prototype is described in D4.1 and the validation of the integration is described in D4.2. The OpenFlow module has been installed in a high-performance PC of the cell at LMS premises which is connected in a common network with the UR10 cobot controller and Hololens AR glasses.

The connection and integration of OpenFlow is based on a set of ROS Action servers available through the local network of the cell waiting for ROS Action goals to be sent from the OpenFlow. Based on the results of the AI task planner module, the OpenFlow send the required ROS Action goals to the available ROS Action servers for the successful execution of each assembly task.

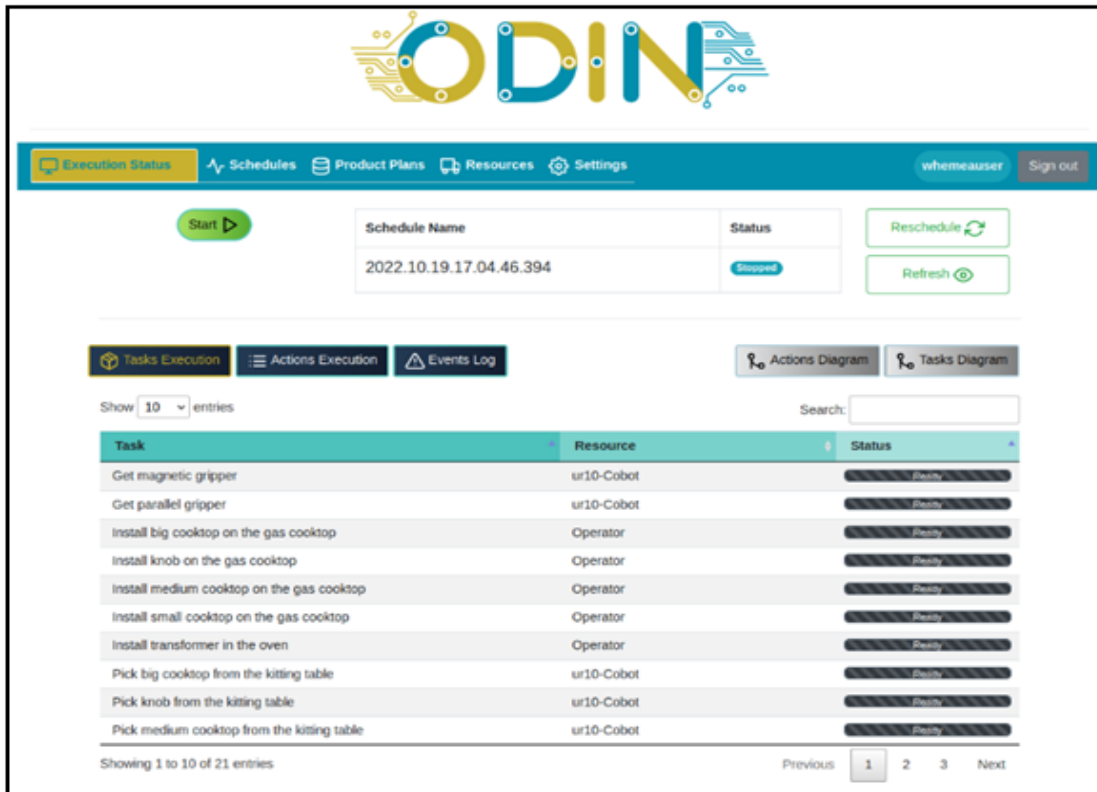


Figure 44: White Goods pilot demonstrator task list in OpenFlow

As documented in section 4.2.1, the current version of ODIN layout at LMS premises is focused on assembly of oven and gas cooktops. The ROS action servers used by the OpenFlow for the execution of the required actions are presented in Table 5.

Table 5. ROS action servers for initial White Goods pilot execution

ROS Action Servers	Description
Move Cartesian Action Server	Action server for the planning and execution of robot motions using Cartesian space goals.
Move Joint Action Server	Action server for the planning and execution of robot motions using Joint space goals.
Configure Payload Execution Action Server	Action server for updating the payload of UR10 robot through ROS when robot carries high payload parts (transformer).
Configure TCP Action Server	Action server for updating the robot end effector through ROS when robot carries parts (move the end effector at the end of the carried part).
Detection Action Server	Action server for the pose estimation of parts need to be manipulated by the robot.
Execute Human Task Action Server	Action server for the connection of AR operator support application with the OpenFlow.
Control Gripper Action Server	Action server for enabling / disabling robot grippers.

The connection of OpenFlow with the aforementioned ROS Action servers and the required ROS Controllers and hardware / software components for the initial White Goods pilot execution is visualized in Figure 45.

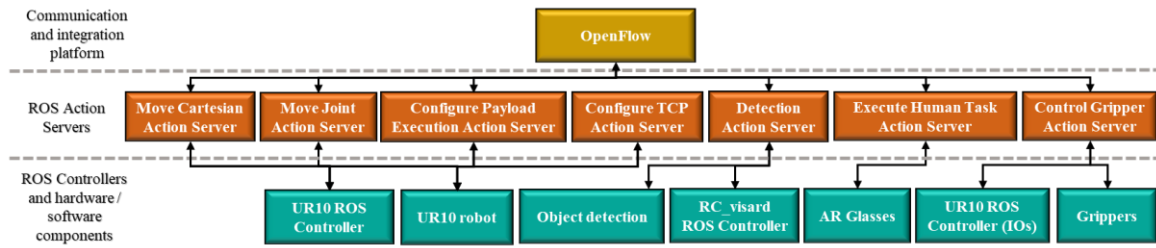


Figure 45. OpenFlow connection with ROS action servers for white goods initial demonstrator

5. CONCLUSIONS

This document has presented the initial version of ODIN Industrial Component focusing on the large-scale pilot lines developed in ODIN. In more details, the integration and testing of ODIN first prototype modules in each large-scale pilot has been detailly presented.

The main conclusion from Open, Digital and Networked Components integration inside ODIN industrial demonstrators at LMS, TECNALIA and AIC premises is that WP5 tasks are running well technically and on time. The following information per each demonstrator presented in this deliverable:

- Layouts designs of the full scales pilot demonstrators in their final and existing form.
- Successful integration of the ODIN Components and individual modules.
- First testing of pilots' execution flow utilizing the aforementioned modules in the existing setups.

The integration of Open, Digital and Networked Components in the three large-scale pilots of ODIN is a work in progress, and the descriptions presented in this deliverable will be enhanced during the development workflow of WP5 and the relevant tasks in this work package.

The refined version of ODIN modules integration in ODIN pilots will be presented in D5.4 which is scheduled to be submitted on M36.

6. GLOSSARY

AI	Artificial Intelligence
AR	Augmented Reality
HW	Hardware
ROS	Robot Operating System
SW	Software
HRC	Human Robot Collaboration

7. REFERENCES

1. Koukas, S., Kousi, N., Aivaliotis, S., Michalos, G., Bröchler, R., & Makris, S. (2022). ODIN architecture enabling reconfigurable human–robot based production lines. *Procedia CIRP*, 107, 1403-1408.
2. Manufacturing Systems: Theory and Practice, 2nd Edition, Springer-Verlag, New York, New York, (2006)
3. Makris, S., Michalos, G., Kousi, N., Papavasileiou, A., Campos, U. E., Bravo, J. O., ... & Koukas, S. (2022). Open-Digital-Industrial and Networking pilot lines using modular components for scalable production–ODIN project approach. *Procedia CIRP*, 106, 162-167.
4. COMAU AURA Cobot, [Online]. Available: <https://www.comau.com/en/competencies/robotics-automation/collaborative-robotics/aura-collaborative-robot/>
5. COMAU Racer 5 Cobot, [Online]. Available: <https://www.comau.com/en/competencies/robotics-automation/collaborative-robotics/racer-5-0-80-cobot/>
6. COMAU Agile, [Online]. Available: <https://www.comau.com/en/competencies/robotics-automation/collaborative-robotics/automatic-guided-vehicles-agv/>
7. „MVTech: HALCON DL Toolkit,“ [Online]. Available: <https://www.mvtec.com/products/halcon>.
8. „Online documentation of Roboception CADMatch software,“ [Online]. Available: <https://doc.rc-cube.com/latest/en/cadmatch.html>.
9. „Online documentation of Roboception SilhouetteMatch software,“ [Online]. Available: <https://doc.rc-cube.com/latest/en/silhouettematch.html>
10. „Online documentation of WINGMAN tool changer system,“ [Online]. Available: <http://triplea-robotics.com/>.