Mobile dual arm robotic workers with embedded cognition for hybrid and dynamically reconfigurable manufacturing systems

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Summary:

This document provides a description of the hardware and software customization required during the execution of the aeronautics pilot case. It includes the required adaptations for the pilot case transference in AERNNOVA premises.

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1. EXECUTIVE SUMMARY

The status of THOMAS aeronautics pilot case layout will be detailly described in this deliverable. From the beginning of the project, one simulated 3D environment has been designed (Figure 1) for the aeronautics pilot case and used for testing all THOMAS developed technologies. For a proper evaluation of the simulation results, the CAD files of the real hardware components and controlling systems of THOMAS Mobile Robot Platform (MRP) are used. This simulated layout was designed based on the characteristics and available resources of the Aeronautics pilot case physical layout which has been deployed in TECNALIA's premises (**Figure 2**). The main target of this document is to describe the progress of Aeronautics pilot case from 3D simulation to the latest version of the pilot cell transferred to AERNNOVA facilities (Figure 3).

Based on the type of the activities executed inside the aeronautics pilot case shop floor, the overall layout of this use case can be divided into three different working areas as presented below:

- Drilling working area
- Sanding working area
- Rivet Inspection working area

Despite the fact that the first prototype of the MRP does not integrate all the safety components that has been developed and integrated in THOMAS project, based on project's officer comments, a minimum safety measures have been implemented in the MRP n1 for guarantying the safety of the operators and the equipment. In the last section of this document the implemented measures will be presented.

Figure 1: Simulated environment of THOMAS Aeronautics pilot case at AERNNOVA

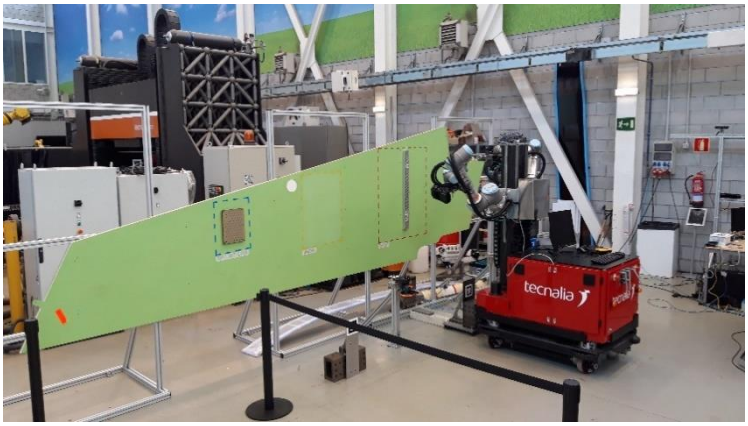


Figure 2: Actual environment of THOMAS Aeronautics pilot case at TECNALIA

Figure 3: Actual environment of THOMAS aeronautics pilot case at AERNNOVA

2. INTRODUCTION

Current document starts presenting THOMAS aeronautics simulated layout (Section 3.1). Then, the three principal use cases selected for THOMAS project are presented: drilling, sanding, and rivet inspection. In order to demonstrate the capabilities of the THOMAS MRP, AERNNOVA has provided a typical airplane wing for implementing selected processes in the most realistic way. The wing has been virtually divided in three parts where each use case is demonstrated. Section 3.2 contains the drilling working area; Section 3.3 deals with sanding working area; and finally, Section 3.4 presents the rivet inspection working area. In the Section 3.5 the integrated and exchangeable components of the THOMAS MRP are presented.

The current state of the physical layout is presented in Section 4 of this deliverable. In the contained subsections the different use cases details are showed: Section 4.2 contains the drilling use case, Section 4.3 focusses on sanding use case, and Section 4.4 is centred in rivet inspection use case. Finally, the required modifications to the pilot cell transferred to AERNNOVA are presented in Section 4.5.

3. THOMAS AERONAUTICS USE CASE LAYOUT

3.1. General Overview

The latest version of THOMAS Aeronautics use case layout has been designed and inserted in the 3D simulation environment of the scenario. The use case is divided in 3 areas:

- Drilling working area
- Sanding working area
- Rivet Inspection working area

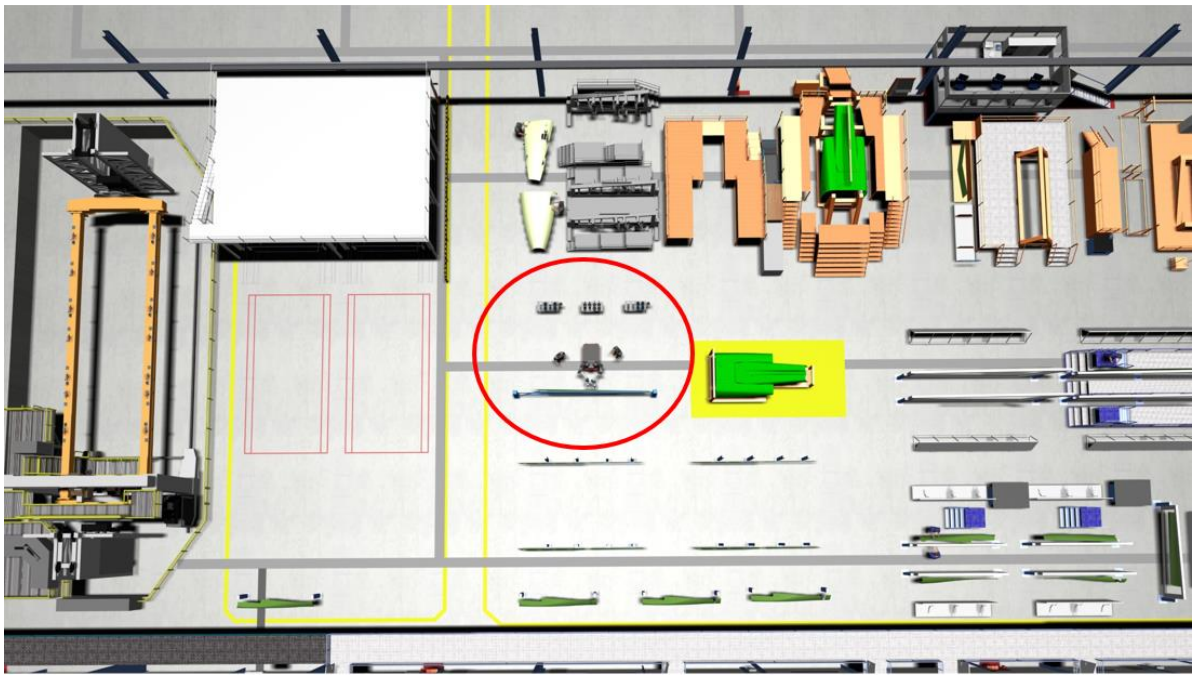


Figure 4: Layout of the plant where the THOMAS use-case is located

In the final Aeronautics pilot case, the demonstration of the three operations will be done over one wing divided into three different areas. Figure 4 shows the layout of the AERNNOVA plant where the wing will be located. Figure 5 and Figure 6 show a more detailed view of THOMAS aeronautic pilot case working area.

Figure 5: Detailed view of the pilot case area with the three tool exchanging places (in the actual pilot cell the exchanging places are near to the wing, see Section 4.5 for more details)

Figure 6: Detail of a simulated drilling operation example layout

3.2. Drilling working area

The drilling process consists of making the joining holes of both skins to the inner structure (ribs and spar) (Figure 7) using drilling templates (Figure 8) that are positioned and removed by the operator. THOMAS solution combines the installation of drilling templates and drilling operation in cooperation between the MRP and the operator. More details about this operation were presented in deliverable D1.1.

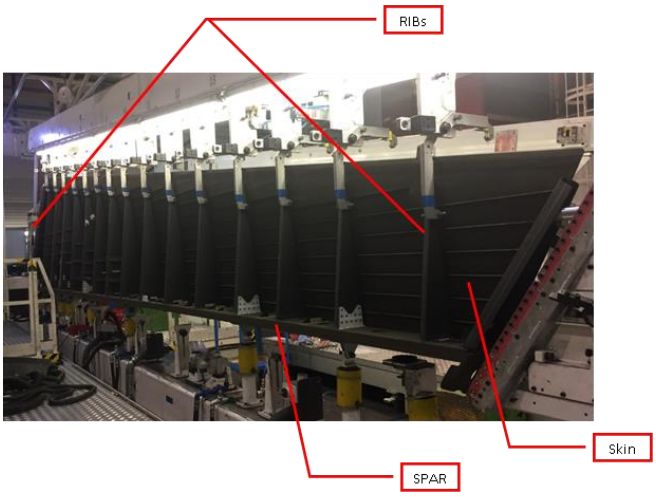


Figure 7: Inner structure

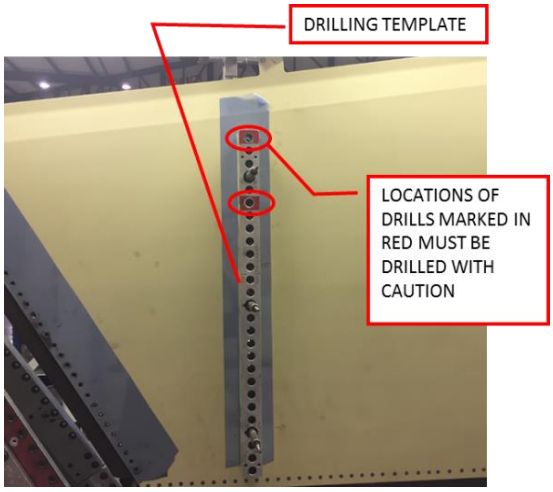


Figure 8: Drilling template

Human operator is responsible for drilling templates' installation (Figure 9).

Figure 9: Human operator installs a template

The MRP navigates to the drilling area. Then, as described in Deliverable D3.2, the in-cell navigation module is used in terms of efficient navigation actions of MRP in the drilling area. This module requires the detection of an AprilTag placed inside of the front camera's field of view (Figure 10).

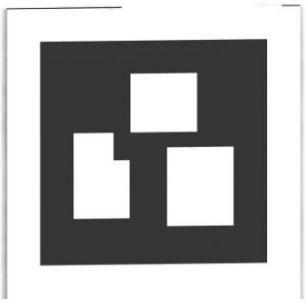


Figure 10: AprilTag for the in-cell navigation module in drilling working area

The MRP attaches the drilling tool to its arm. One AprilTag has been placed on the tool exchanging area. The robot detects the AprilTag and uses it to detect the drilling tool and move the arm to a desired position in order to perform grasping action. Regarding the drilling operation, first of all, MRP locates the template and its holes using THOMAS artificial vision system (Figure 11). After the detection process, MRP performs drilling operation using the equipped driller unit.

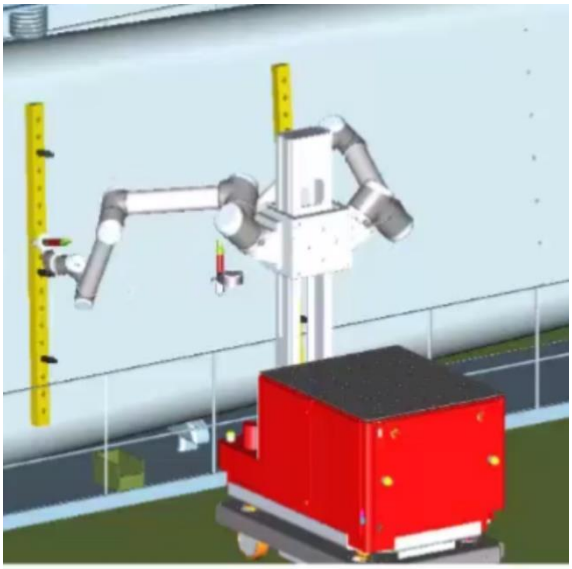
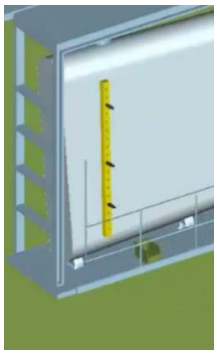
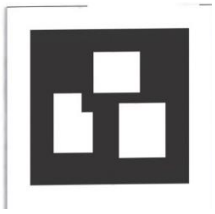


Figure 11: MRP performing drilling operation

Table 1: Hardware components and their role in the drilling working area

Hardware component	Use	Resource assigned for this task	CAD model
Drilling Template	Template for drilling	HUMAN – MRP	
AprilTag No1	In-cell navigation to drilling area	MRP	

3.3. Sanding working area

For the sanding operation the robot could be equipped with two sanding machines to process a surface. There is a continuous feedback from the robot to the operator in order to achieve a rapid decision making in working process (robot continue/stop working) and changing the predefined sanded map to move the robot to a location for a specific sanded work.

Figure 12: Human paint sanding operation

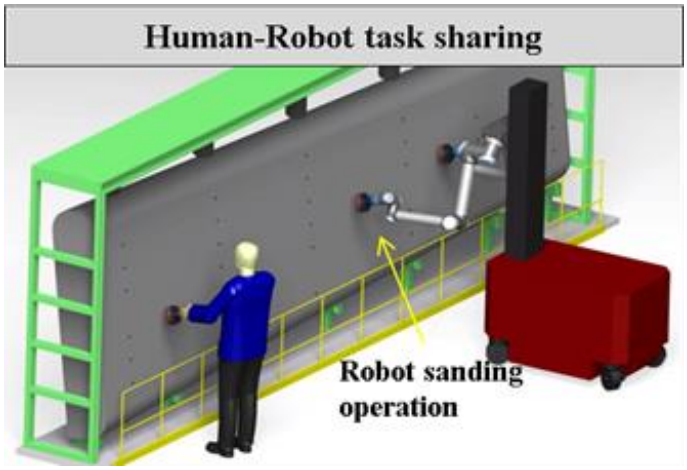


Figure 13:Sanding operation performed in cooperation with MRP and operator

The MRP navigates to the sanding area following the same procedure as described in the previous section by using one AprilTag which has been placed inside one camera's field of view (Figure 14). Then the robot proceeds to perform the sanding operation.

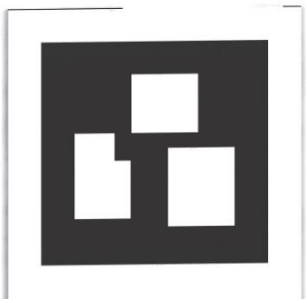


Figure 14: AprilTag for the in-cell navigation module in sanding working area

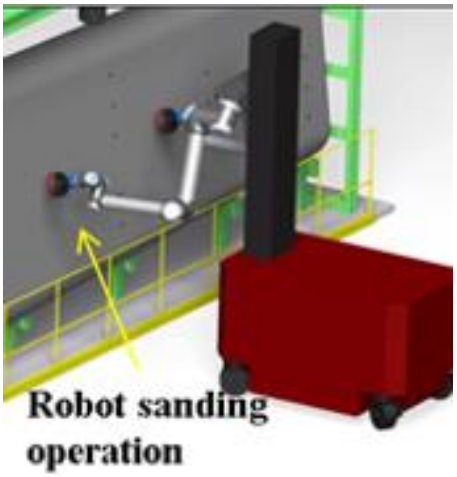


Figure 15: Robot performing sanding operation

Table 2: Hardware components and their role in the sanding working area

Hardware component	Use	Resource assigned for this task	CAD model
AprilTag No1	In-cell navigation to drilling area	MRP	

3.4. Rivet Inspection working area

The Robot inspects the height of the rivets with a scanner installed in one of its arms. In case that any of the rivets is not in the correct height, robot will mark it on the skin product. This rivet must be repaired and inspected again, until 100% of defects have disappeared. The goal on this scenario is to show the flexibility of THOMAS approach. At the beginning of the rivet inspection process, MRP navigates to the corresponding area. Then, as described in Deliverable D3.2, the in-cell navigation module is used in terms of efficient navigation actions of MRP in this area. For this purpose, one AprilTag has been placed inside one camera's field of view (Figure 16).

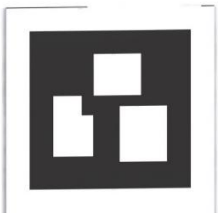


Figure 16: AprilTag for the in-cell navigation module in rivet inspection working area

The surface of the part is scanned for any rivet that is outside the predefined height limits. For this purpose, one camera has been placed on one MRP's arm to detect the different heights. If any rivet is not in the correct height the MRP marks it with a marker placed on the other arm of the MRP (Figure 17).

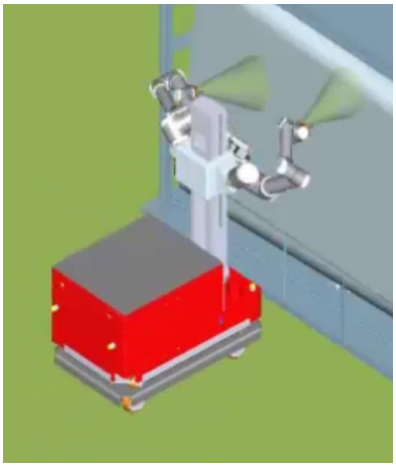


Figure 17: MRP performing rivet quality inspection operation

Table 3: Hardware components and their role in the rivet inspection working area

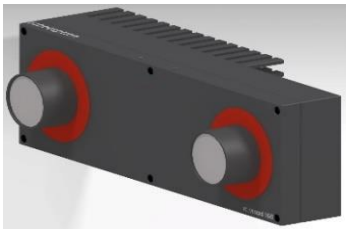
Hardware component	Use	Resource assigned for this task	CAD model
AprilTag No1	In-cell navigation to drilling area	MRP	

3.5. THOMAS Mobile Robot Platform's (MRP) components

The hardware components related to the MRP have been divided into two groups. Those that are fixed on the robot arms and those that are part of detachable tools that the MRP will take at each of the working areas.

3.5.1. Fixed hardware placed on the MRP

Table 4: Hardware components fixed at the MRP

Hardware component	Use	Robot Configuration	CAD model OR real picture
ROBOCEPTION rc_visard 160 stereo camera	Template detection	Left arm (aeronautics use case)	

ROBOCEPTION rc_visard 65 stereo camera	Precise hole detection	Right arm (aeronautics use case)	
Intel RealSense 3D camera	3D obstacle detection for navigation	Torso of the MRP	
IDS CAMERA	AprilTag detection for static docking	Front of the robot	
OnRobot force control sensor	Guarantee the surface alignment and applied forces for sanding	Depending the number of sanding machines (typically in the right arm)	
Schunk exchangers	Allow quick and safe tool exchanging	Left and right arms	

3.5.2. Exchangeable tools required for each operation

3.5.2.1. Drilling operation

For drilling operation. The robot uses the two ROBOCEPTION cameras from the fixed equipment of the robot. And the SetiTec ADU as a removable hardware which is taken from the tool exchanger situated in from of the working area. This decision is motivated due to the different diameters of the holes that could be drilled depending on the part to be processed. Thus, multiple ADU could be used by the MRP. Besides, the driller machines require external vacuums for residues handling and external compressed air supply.

Table 5: Exchangeable tools for drilling operation

Hardware component	Use	Robot Configuration	CAD model OR real picture
SETITEC ADU	Preform drillings	Right arm	

3.5.2.2. Sanding

One pneumatic sanding machine is required in order to perform the sanding operation. As before the sanding machines require external vacuum systems plus external air supply.

Table 6: Exchangeable tools for sanding operation

Hardware component	Use	Robot Configuration	CAD model OR real picture
Pneumatic sanding machine	Sanding surface	Installed in both arms for to reduce the cycle time	

3.5.2.3. Rivet inspection

For riveting inspection, the robot could use different exchangeable sensors depending of the required precision or field of view.

Table 7: Exchangeable tools for rivet inspection operation

Hardware component	Use	Robot Configuration	CAD model OR real picture
Gocator profilometer 2520A	Determine if the installed rivets comply with the required tolerances	Left arm	
Gocator snapshot 3210	Determine if the installed rivets comply with the required tolerances	Left arm	

4. THOMAS AERONAUTICS SET UP

4.1. General Overview

THOMAS Aeronautics pilot case preliminary setup was constructed in TECNALIA and DGH premises based on the simulated layout presented in section 3. Available components of THOMAS Aeronautics pilot case in TECNALIA and DGH premises are presented in the next 3 subsections.

Considering the simulation presented in Section 3.1 and the space allocated in TECNALIA's premises, the cell presented in Figure 18 has been developed using CATIA software. This 3D design has been used not only for construct the actual one, but also for the Easy Task Programming Framework. A real part of an aircraft wing has been hold using standard Bosch profiles. The wing has been divided into three zones where previously mentioned task will be demonstrated (Figure 19). After the testing and developing phases, the demonstrator has been transferred to AERNNOVA facilities. There the three use cases have been demonstrated in a similar wing and workspace, as can be seen in Figure 20.

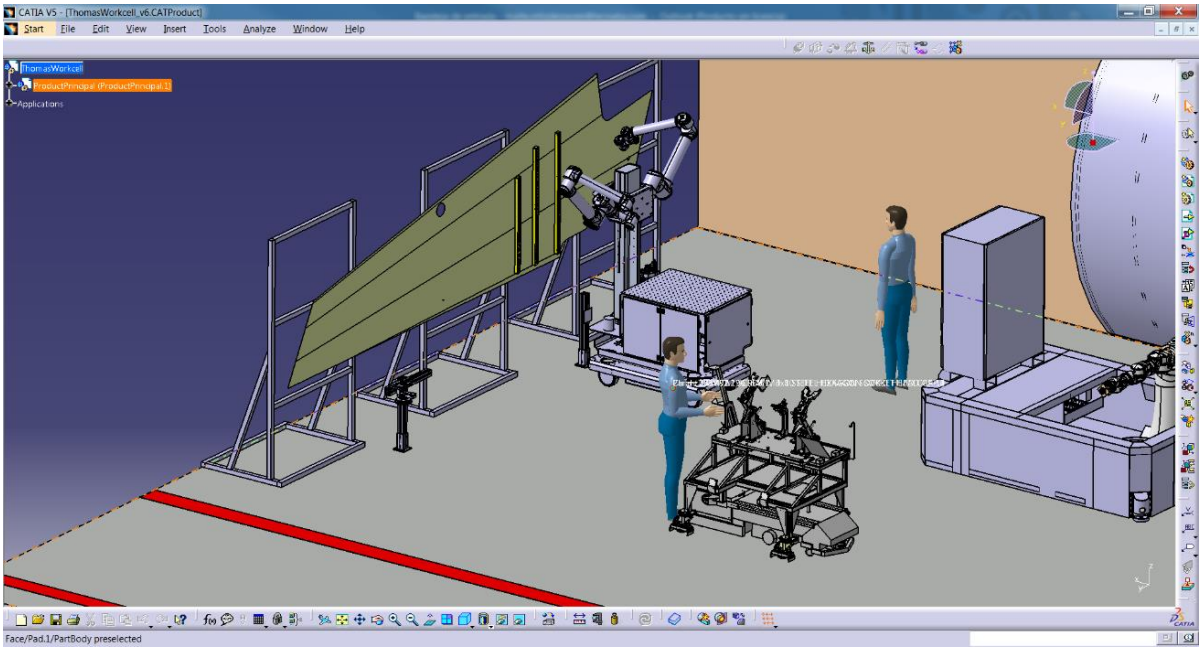


Figure 18: 3D Simulated cell developed in Catia for multiple purposes

Figure 19: Aeronautics pilot cell at TECNALIA's premises. The wing is divided into three zones

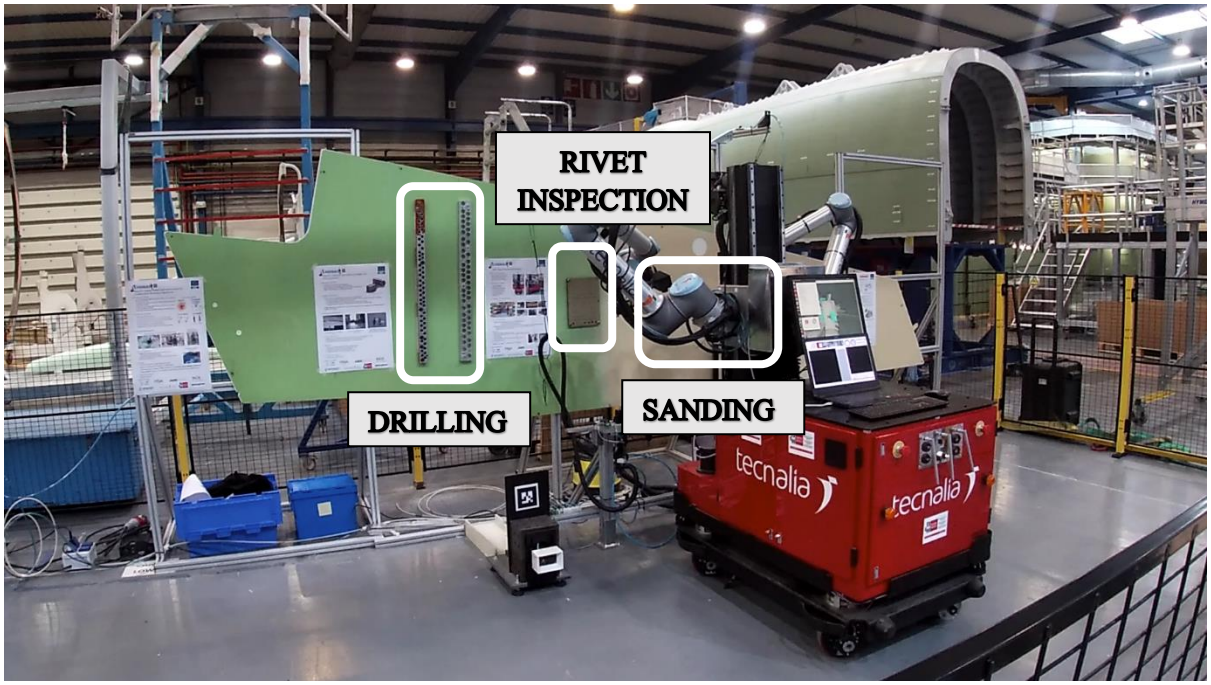


Figure 20: Aeronautics pilot cell at AERNNOVA's premises

4.2. Drilling working area

For demonstrating the drilling operation, in the biggest part of the wing (right side), the different drilling templates have been fixed (Figure 21). Below, it incorporates the robot docking system that contains an AprilTag for precise positioning. The following sections show the different stages of the operation, starting from task programming and finishing with the required drillings.

Figure 21: Drilling working area

4.2.1. Easy Task Programming

Through the developed CATIA based GUI for CAD Programming (see Figure 22) an Easy Task Programming can be achieved. The developed interfaces allow parametrizing and configuring a set of skills that envelope the required sequence of movements and actions of the MRP. For more details please refer to D4.4 where CAD based programming and Skill Based Programming are presented.

Figure 22: CAD Programming GUI

4.2.2. Navigation to the drilling area

Following the philosophy of THOMAS project, the MRP is a robotic mobile platform that can be used for a various set of purposes. Thus, the MRP can be in any different locations of the workshop performing different type of tasks. When its support is required for drilling operation, the cell-to-cell navigation skill allows moving the platform along the workshop avoiding the possible collisions (Figure 23: Cell-to-cell navigation). For more details, please refer to D3.6 where cell-to-cell navigation modules are presented.

Figure 23: Cell-to-cell navigation

4.2.3. Static docking for precise positioning

When the MRP arrives to required cell an in-cell navigation is required for performing a static docking in a specific module which can provide both compressed air and electrical power. The front camera of the MRP tracks an AprilTag located in the docking station. The positioning algorithm is based on the detection and correction of the position of the MRP by a proportional control based on a given reference (see Figure 24). For more details, please refer to D3.6 where in-cell navigation modules are presented.

Figure 24: In-cell navigation for docking operation

4.2.4. Tool exchange

The MRP can be equipped with a diverse set of tools for accomplishing all the proposed challenges in THOMAS project. Thus, an automatic tool exchanging skill is required. Thanks to tool exchanging skill the MRP can grasp the Setitec drilling machine required for drilling operation. Through the rc_visard 65 sensor installed in the right arm of the MRP, an AprilTag located in the tool warehouse is detected and the desired tool can be exchanged (see Figure 25). For more details please refer to D4.5 where the implementation of the skill is presented.

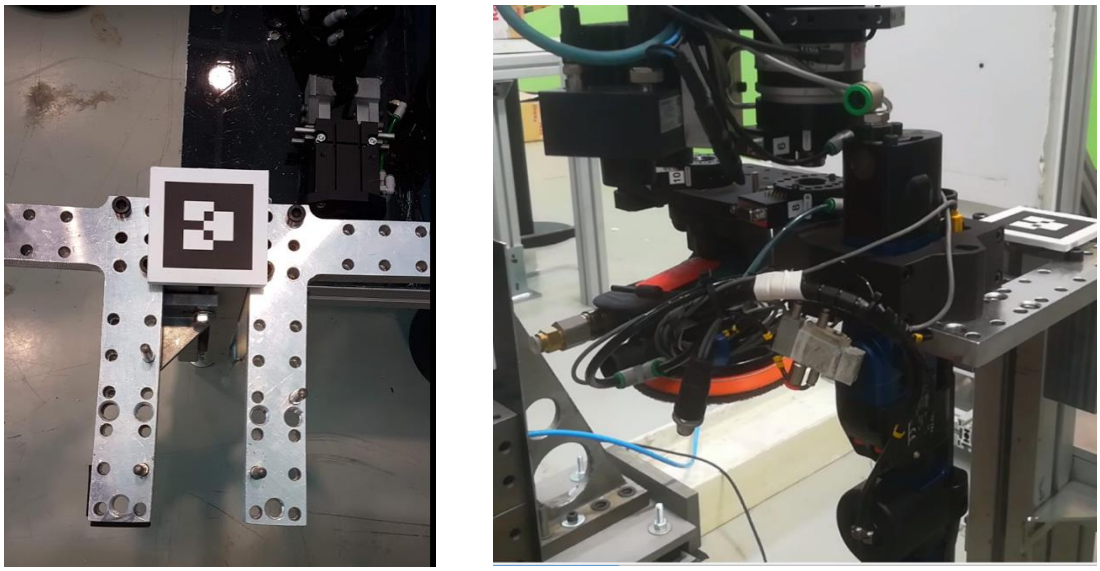


Figure 25: Tool exchanging process

4.2.5. Location of the drilling template and the holes to be drilled

After the MRP has been positioned in the drilling area and has been equipped with the appropriate tool the drilling templates and the holes must be detected. This process is done in two phases: on the one hand, the template localization through the rc_visard 160 sensor for a coarse detection (Figure 26); on the other hand, with the rc_visard 65 the precise detection of the holes is done (Figure 27). More details of this perception modules can be found at D3.5.

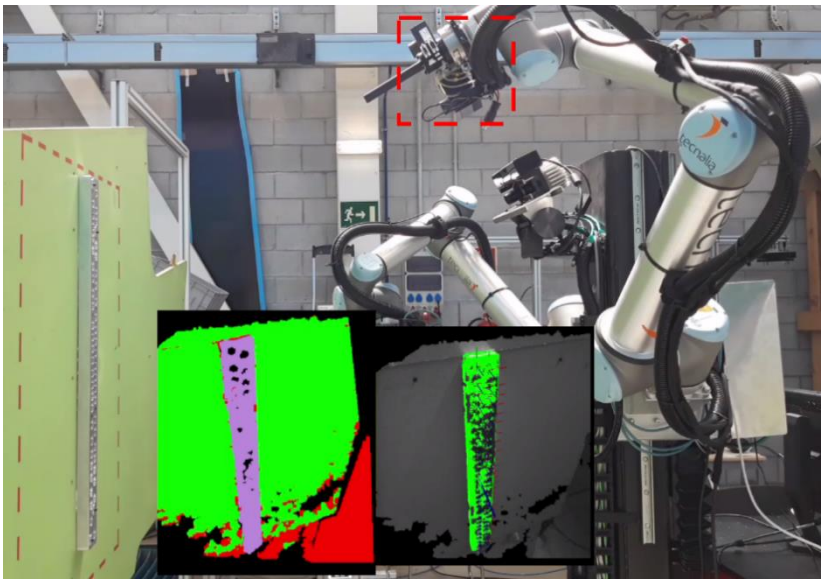


Figure 26: Template detection using rc_visard 160 sensor

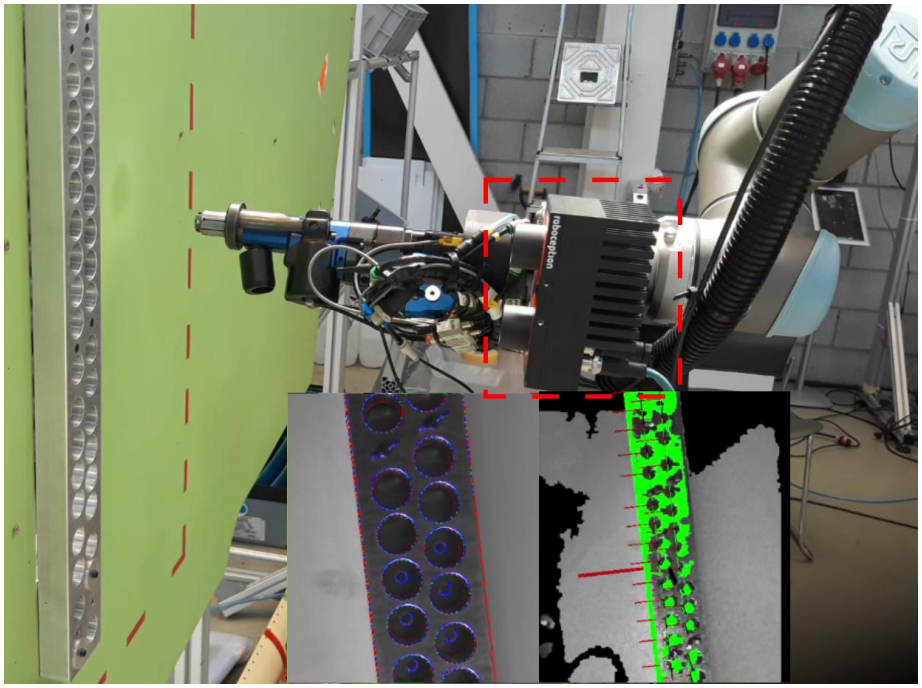


Figure 27: Hole detection using rc_visard 65 sensor

4.2.6. Multiple template detection

One of the drilling use case's objectives is the detection of multiple templates in a single shot, this is motivated by reducing the cycle time and joining the human interventions in the same time slots. As can be seen in Figure 28 different template shapes can be located one near to each other.

Figure 28: Multiple template configuration

The template detection software developed by ROBOCEPTION is able to detect different instances of the same template or different template references. In Figure 29 (left) the segmentation of the pointcloud image can be seen. Then, the CAD matching process is presented (right).

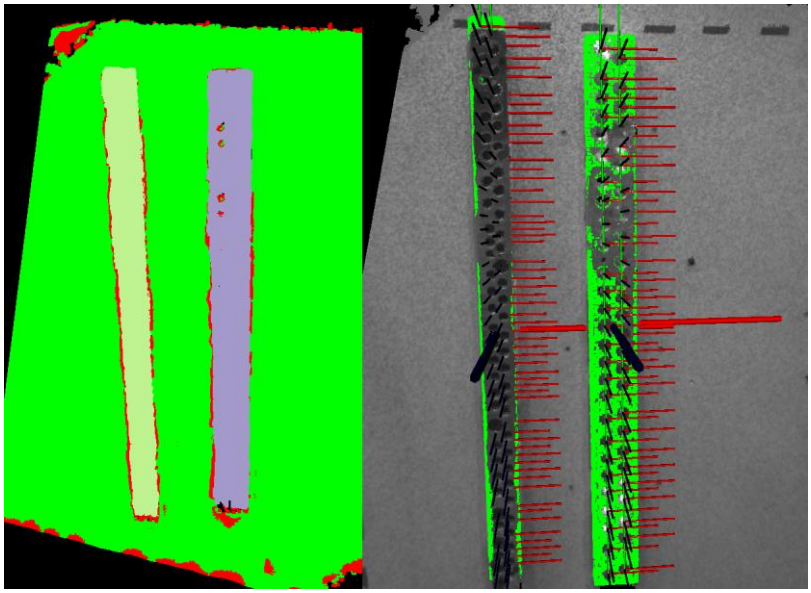


Figure 29: Point cloud segmentation (left). CAD matching of different templates (right).

At Figure 30 the pose optimization can be appreciated. This optimization is done in the last step for achieving higher precision.

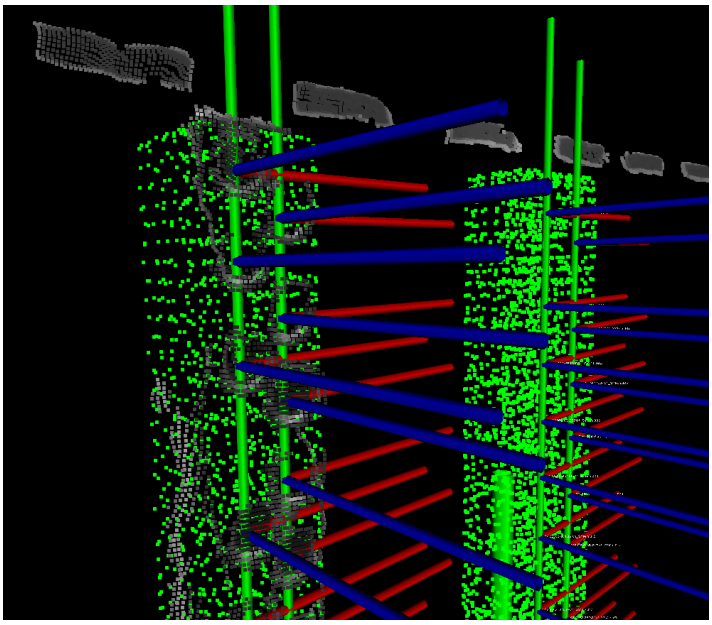


Figure 30: CAD models of different templates are precisely aligned to the detected point cloud.

4.2.7. Drilling

The last phase of the drilling task is the drilling operation itself. This step consists on introducing the drilling machine in the detected holes maintaining constantly the perpendicularity of the insertion. Maintaining the appropriate orientation is imperative, otherwise the driller machine would stuck in the template. After the insertion the concentric collet of the machine expands and assures the perfect alignment of the drilling (Figure 31).

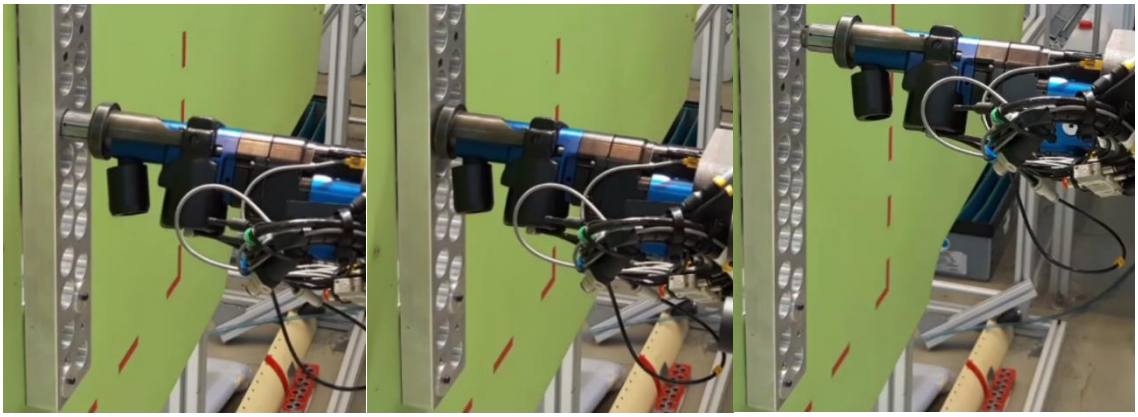


Figure 31: Drilling operation

For being able to perform multiple experiments in the same aeronautic part (the wing mounted in a profile-based structure), a set of aluminium plates or coupons have been used for drilling, instead of drilling the actual wing. In the Figure 32 the results of the drillings are presented.

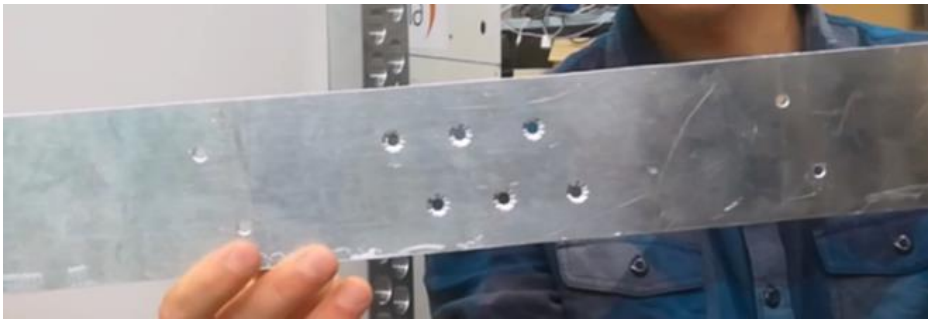


Figure 32: Drilling results on aluminium test plates.

4.2.8. Drilling operation at AERNNOVA pilot cell

Figure 33 shows the drilling pilot case at AERNNOVA's facilities.

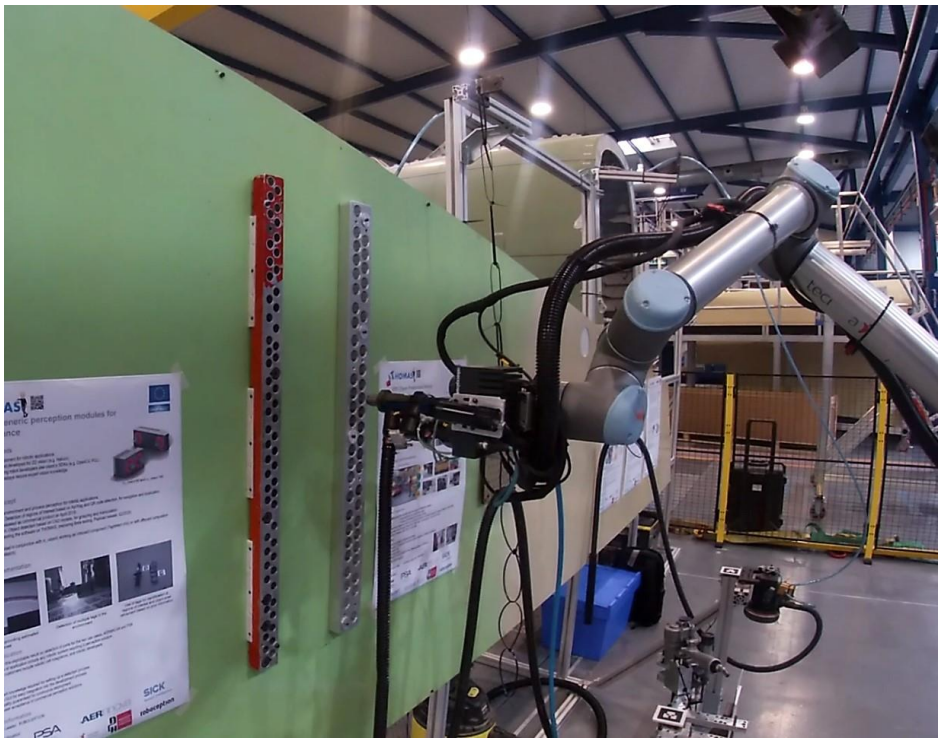


Figure 33: Drilling use case at AERNNOVA's facilities

4.3. Sanding working area

For testing the sanding system, several layouts have been prepared in order to test different types of parts. First tests have been completed over fake parts and then the system has been tested over real parts. The following pictures present the layouts for the different tests performed for sanding.

4.3.1. Layout for testing the sanding operation over mockup parts

A specific layout has been designed in DGH's premises in order to test the sanding operation. The main target of this experiments was to perform the sanding operation on curved surfaces. For this purpose, some metallic patterned parts have been installed in this layout as presented in Figure 34 and Figure 35.

Figure 34: Sanding testing over metallic part flat zone

Figure 35: Sanding testing over metallic part curved zone

4.3.2. Layout for testing the sanding operation over the real scenario parts

Sanding process has been tested on the real parts of the aeronautic pilot case after its successfully test over metallic curved surfaces. As is it presented in Figure 36 and Figure 37 the shape of the actual parts is more challenging, however, the OnRobot force/torque sensor equipped in the left arm of the robot allows following the surface of the parts assuring a constant pressure and contact.

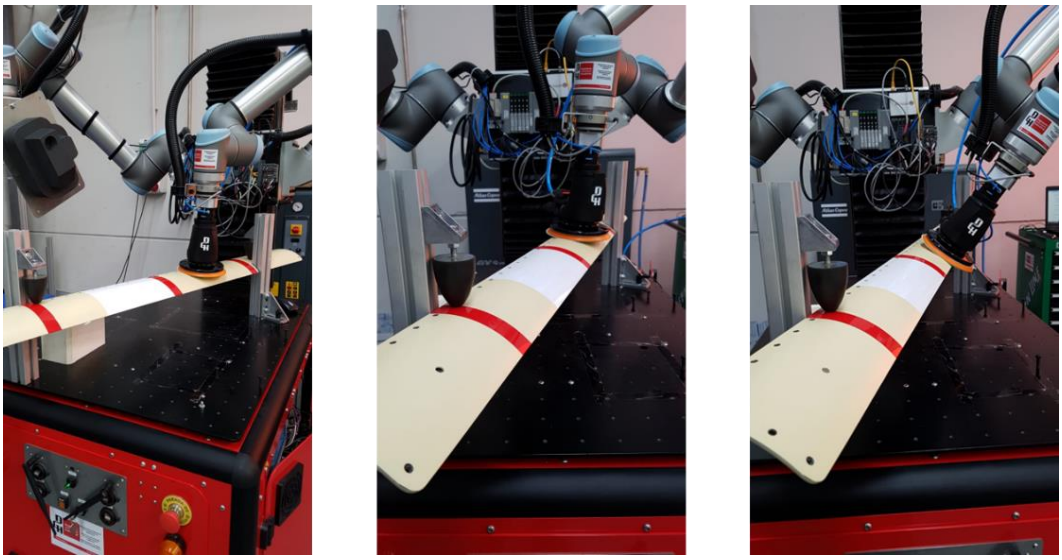


Figure 36: Sanding tests over aeronautics real semi-curved part

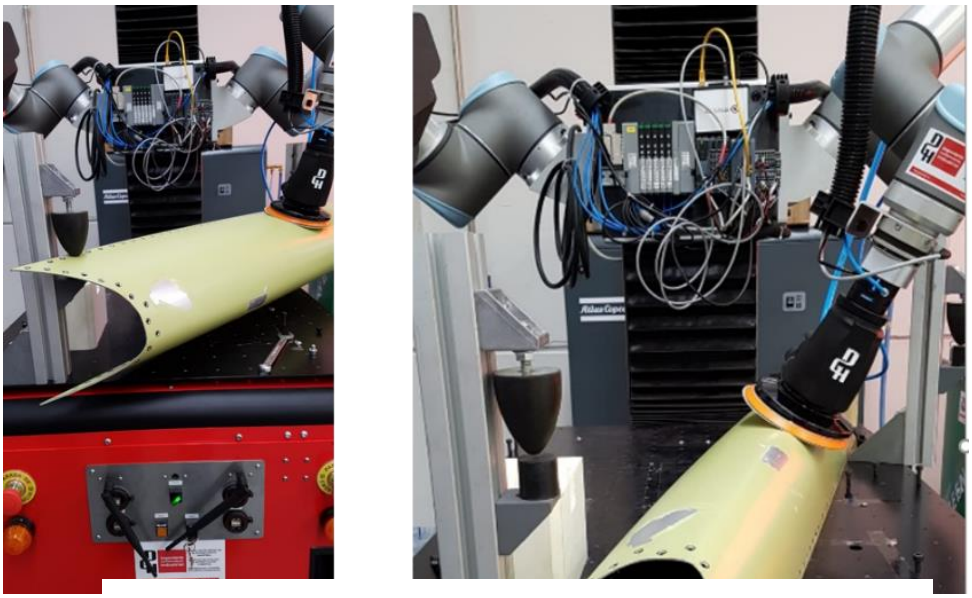


Figure 37: Sanding tests over aeronautics curved parts

4.3.3. Layout for testing sanding operation over TECNALIA's pilot cell

After the experiments performed at DGH's premises for validating the feasibility, the technology has been transferred to TECNALIA's MRP and pilot cell. For demonstrating the sanding operation, the central section of the wing has been allocated (see Figure 38).

Following the same structure than in the drilling process the sanding process starts with an easy programming task; then the navigation and precise docking is required; after that, the tool exchanging process is performed for attaching the appropriate tool (sanding machine); and finally, the sanding process starts in the allocated surface in front of the MRP (Figure 39). In this image the sanded zone and not sanded zones can be appreciated. After a refinement of the force sensor's PID for assuring the

surface alignment, the sanding results have been improved considerably. If the result is compared with previous experiments done in AERNNOVA facilities (Figure 40 left) the improvement can be clearly appreciated (Figure 40 right).

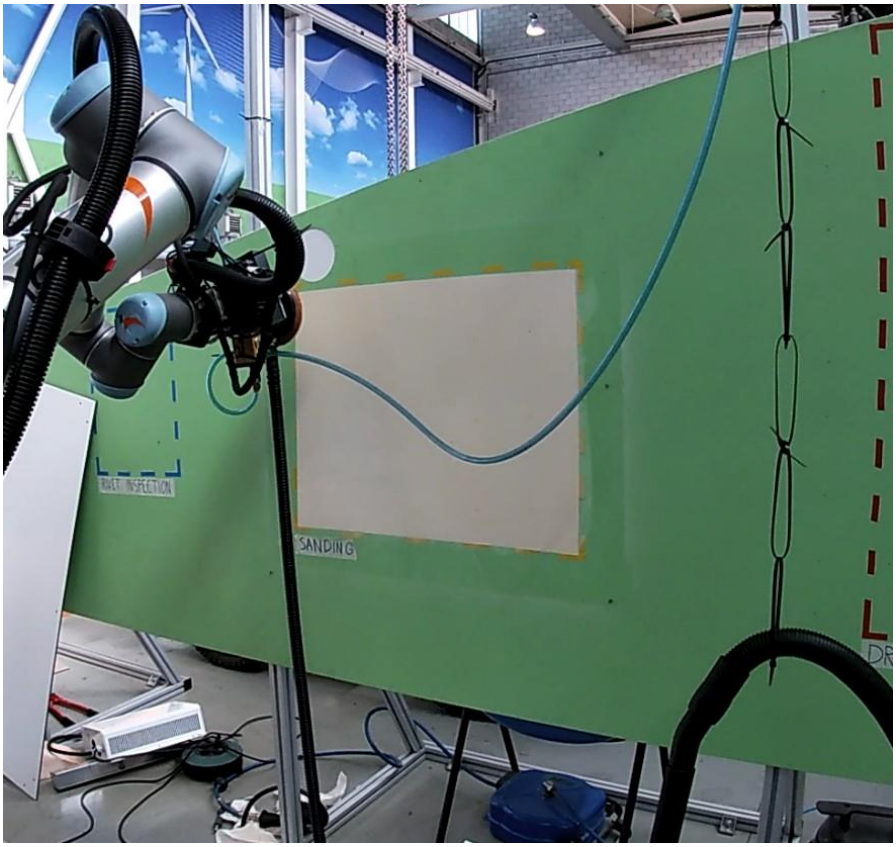


Figure 38: Sanding working area

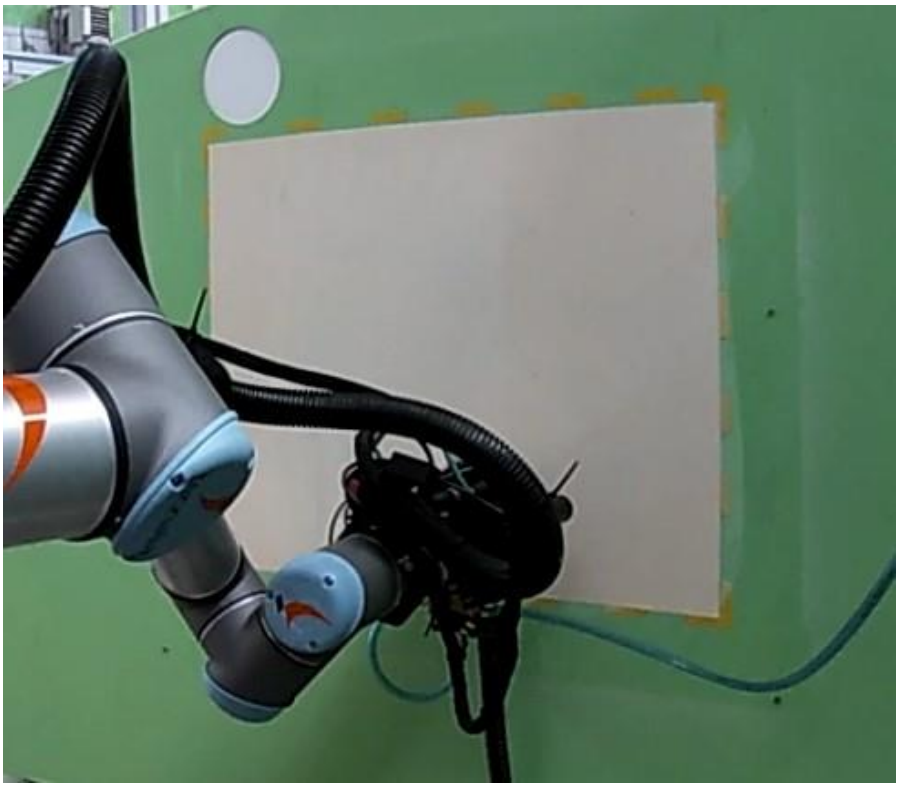


Figure 39: Detail of sanding process. Not sanded and sanded zones can be appreciated

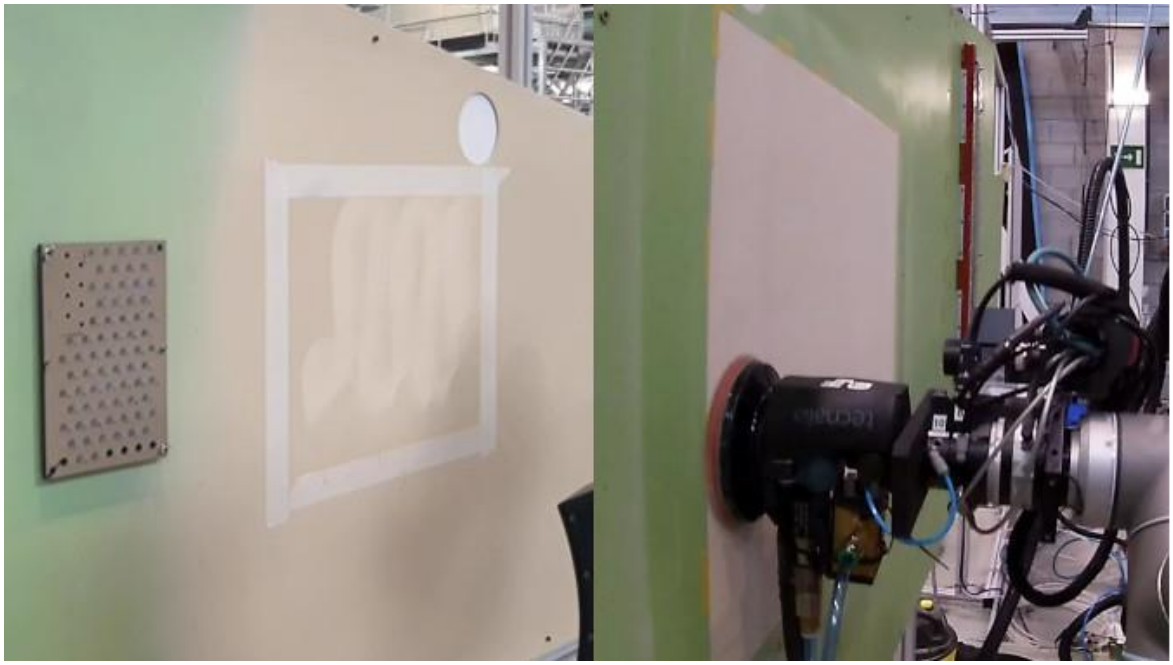


Figure 40: Previous sanding results (left). Optimized sanding operation in a flat surface. The result is much more homogeneous (right).

4.3.4. Sanding operation at AERNNOVA pilot cell

Figure 41 presents the transferred pilot case in AERNNOVA premises.

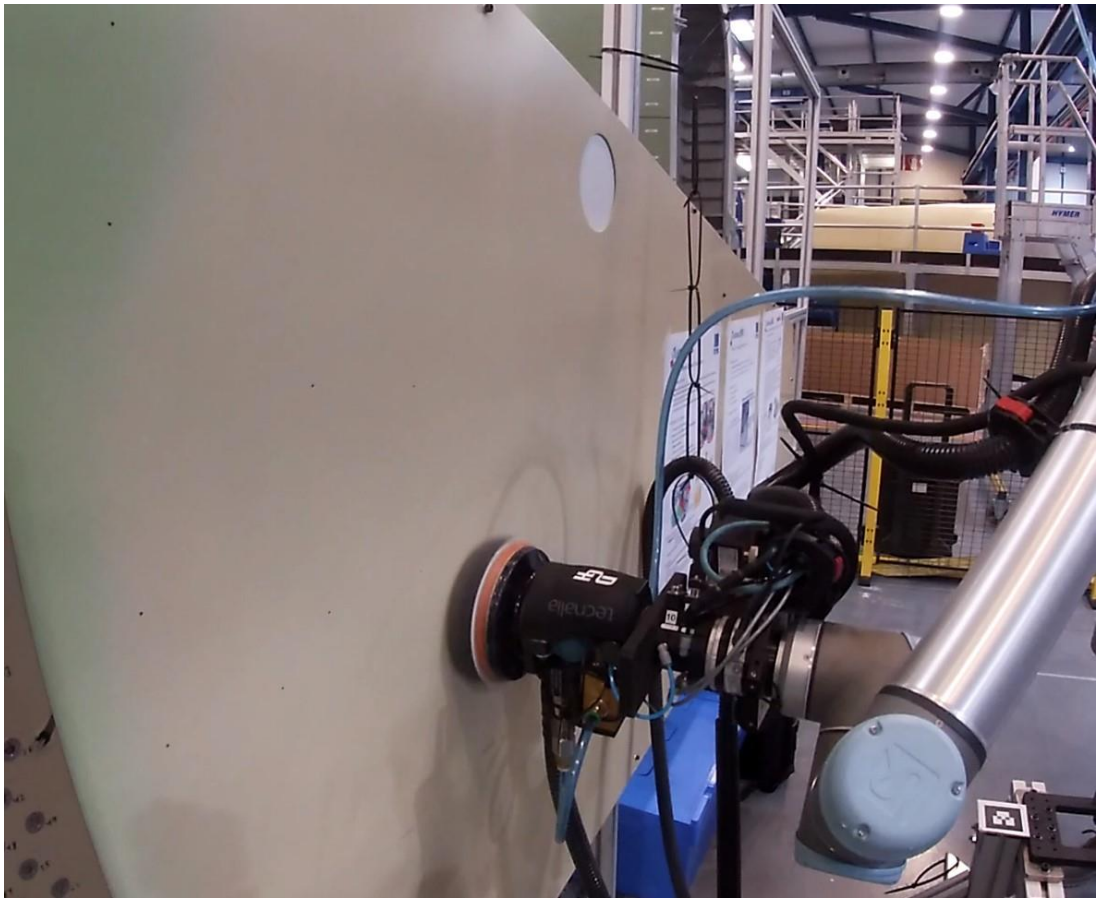


Figure 41: Sanding pilot cell at AERNNOVA premises

4.4. Rivet Inspection working area

Rivet inspection working area is located in the smallest section of the wing (left side). The rivet inspection use case has been analyzed as proof of concept. The efforts focused on the drilling and sanding use cases due to the interests of AERNNOVA. In the allocated section a set of rivets have been installed (some of them with defects) to be able to perform different kind of experiments (Figure 42).

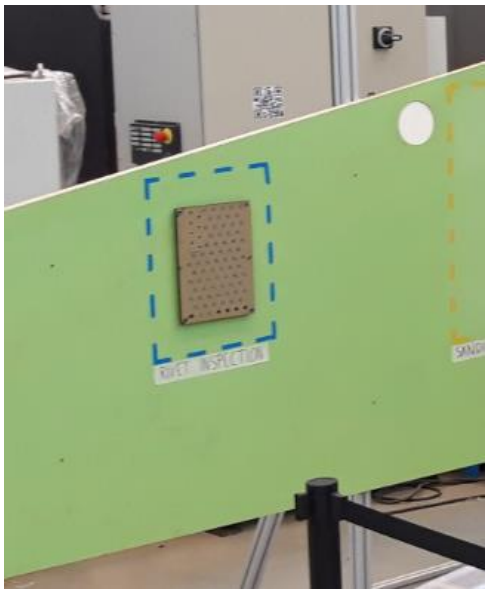


Figure 42: Rivet inspection working area

For these experiments' different sensors were mounted on the robot arm and an execution program has been created for rivet quality inspection. On the one hand, the Gocator 2520A is a profilometer sensor which requires moving along the rivets for acquiring a profile of the surface. On the other hand, the Gocator 3210 performs a snapshot of the part to be inspected, obtaining a bigger field of view in one shot. After validating the technology at DGH's facilities, some tests have been performed at AERNNOVA premises, providing very useful information regarding the capabilities of the tested sensors (Figure 43).

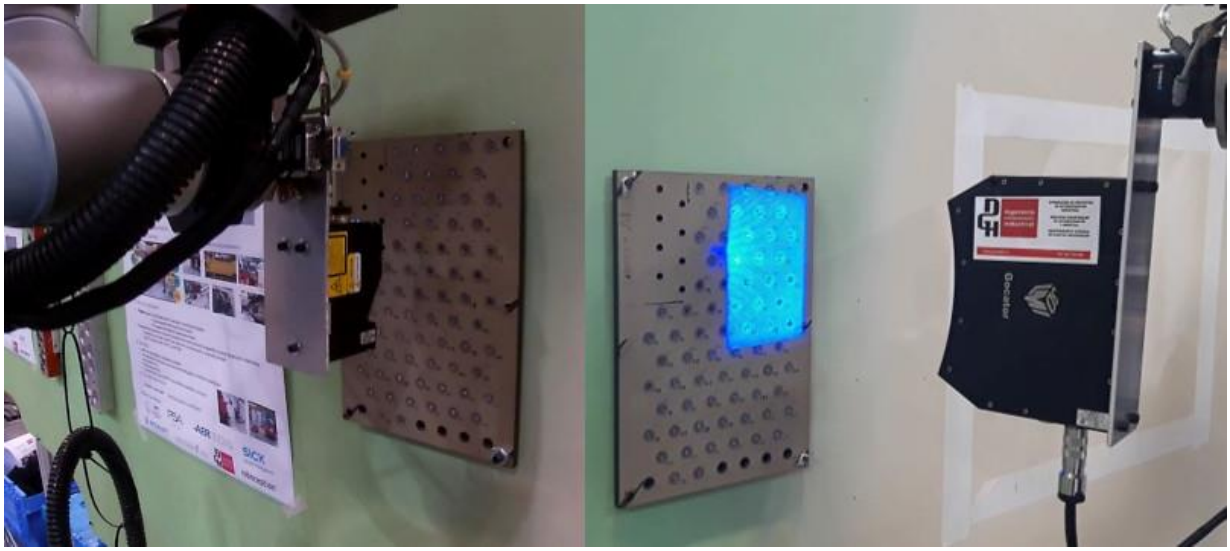


Figure 43: Rivet inspection process using different sensors

4.4.1. Gocator 2520A profilometer test results

The rivet installation quality inspection through a profilometer requires programming trajectories that follows the surface to be inspected. After the initial referencing and setting the inspection zone

parameters, the developed program is ready to be enveloped as skill. In this case the UR script executing skill is responsible to call the inspection program. The inspection with the Gocator 2520A provide a very dense point cloud image, enabling the computer vision algorithms determining if the installation of the rivets is inside of the required tolerances. In the Figure 44 the results of the profilometer pass are presented.

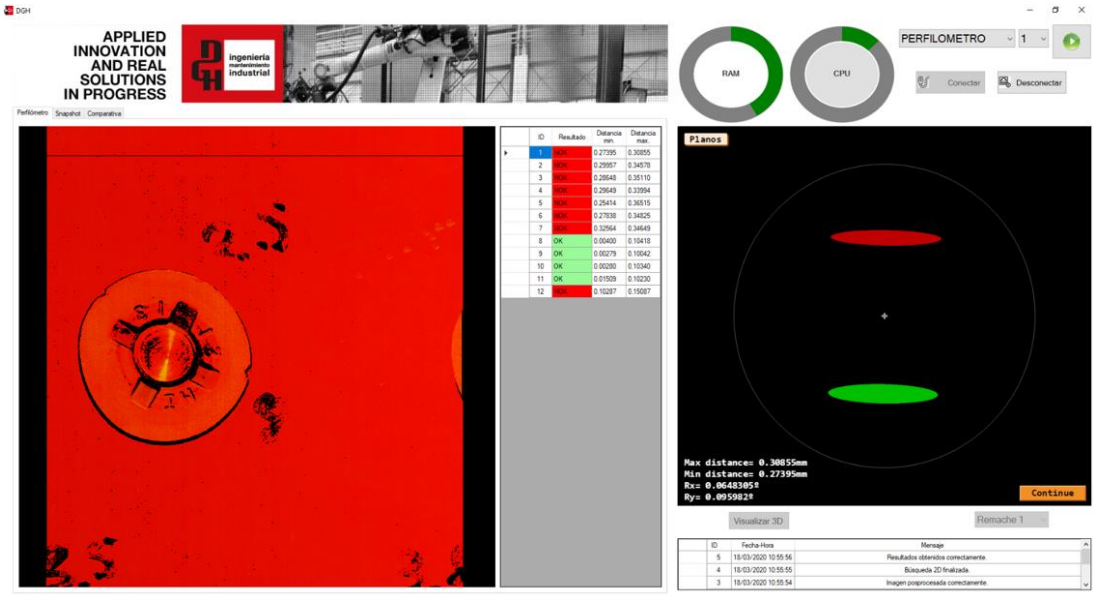


Figure 44: Gocator 2520A profilometer results

4.4.2. Gocator 3210 snapshot camera test results

On the other hand, when the Gocator 3210 snapshot camera is used, different poses for acquiring snapshot must be determined. As before, elaborated programs can be executed through the UR script executing skill. The advantage of the Gocator 3210 is a bigger field of view, at the cost of lower resolution. Even so, the obtained point cloud density is good enough for determining the correct installation parameters (see Figure 45).

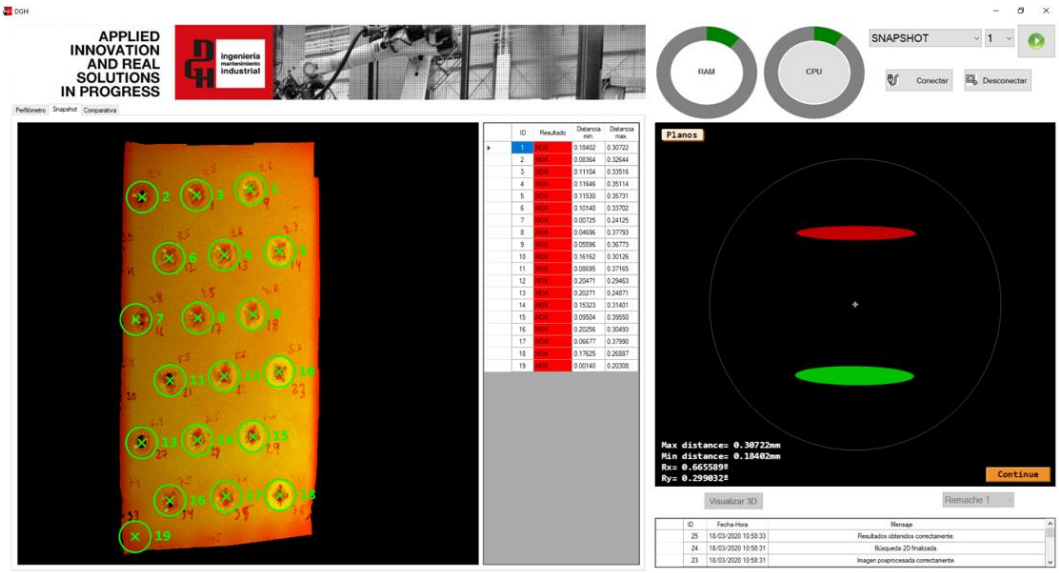


Figure 45: Gocator 3210 snapshot camera results

4.5. Required modifications for transferring THOMAS aeronautics OPS to AERNNOVA premises

4.5.1. Safety

In the aeronautics OPS (Open Production Station) the safety concept is partially demonstrated due to the installed modules on the MRP_n1. Due to the fact that the OPS n2 includes a newer version of the MRP, MRP n2 is equipped with the full safety concept which is demonstrated in the automotive use case. As a result of this, in MRP n1 THOMAS focused to maintain the consistency of the whole system, and the safety systems have been partially integrated.

In order to guarantee the safety in OPS n1, two different safety modes have been implemented, the safety during operation and the safety during navigation. Due to the limited integration of the safety modules, the safety zones' switching must be triggered when the robot docks to a docking station.

4.5.1.1. Safety during operation

The OPS n1 is equipped with two safety laser scanners (SICK S300 laser scanners) placed at the robot corners. These devices' data combination provides a field of view of 360º. They are connected to a general safety relay able to switch down the robot when anything enters in the defined safety fields configured in the laser scanners' field of view. The initial target was to replace the SICK S300 sensors placed on the MRP n1 with Microscan 3 laser scanners but trying to assure the consistency of the whole MRP this migration has been done partially. The laser scanner sensors have been replaced, as well the Flexisoft modules, however the SICK ECU for human detection has not been integrated.

In order to guarantee the safety of the OPS n1, no humans will be able to work close to the robot during any operation's execution. If an operator enters the security limit of safety fields (1.5 meters near UR robots and 0.5 meters behind the MRP) the robot system will enter in emergency stop mode.

4.5.1.2. Safety during navigation

Using the same safety hardware used in the operational mode, for the autonomous navigation, the aeronautics OPS must guarantee the safety of the operators that can be found in the work cell (when OPS is executing in-cell navigation), or in other areas of the shop floor(when is executing cell-to-cell navigation).

With the hardware installed in the OPS n2 the safety zones can be dynamically modified depending on the speed and the direction of the operator but also combined with human detection modules. Based on the fact that all the safety modules have not be integrated in the aeronautics OPS, the safety zones are static (0.5 meters around the whole OPS), reducing the efficiency of the path planner and the navigation stack.

4.5.1.3. Additional safety modules

In order to protect not only the human operators, but different safety hardware have also been installed for protecting the robot equipment and the aeronautic parts. If an emergency occurs in the middle of a process's execution, then all the ongoing operations are aborted by stopping the compressed air flow.

Regarding the sanding operation an additional valve has been integrated for stopping the compressed air flow to the sanding machine when an emergency is detected. The emergency can be triggered from the force sensor when excessive effort is detected or when a general emergency signal is sent from any other component of the OPS. This mechanism stops the sanding machine and avoids damages on aeronautics parts (see Figure 46).

In the case of drilling use case, an electro valve handles the input compressed air flow and stops in case of emergency (Figure 47 left). The electro valve located in the right part of Figure 47 controls the docking air flow and avoids causing damages when the robot docks and undocks from the station.

Related to this, but not strictly related with the safety, a relay has been installed for handling the vacuum system. In this way the vacuum is only activated when the operations are in progress, reducing considerably the generated noise in the pilot cell (Figure 48).

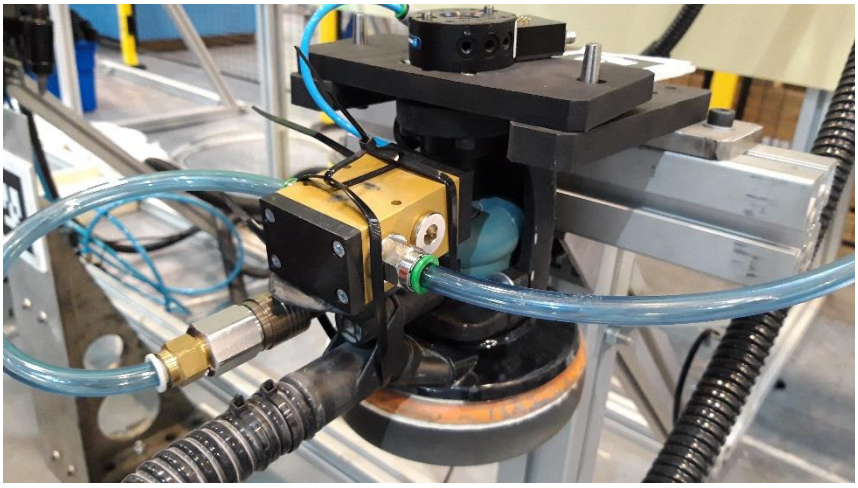


Figure 46: Safety valve for stopping air compressed flow

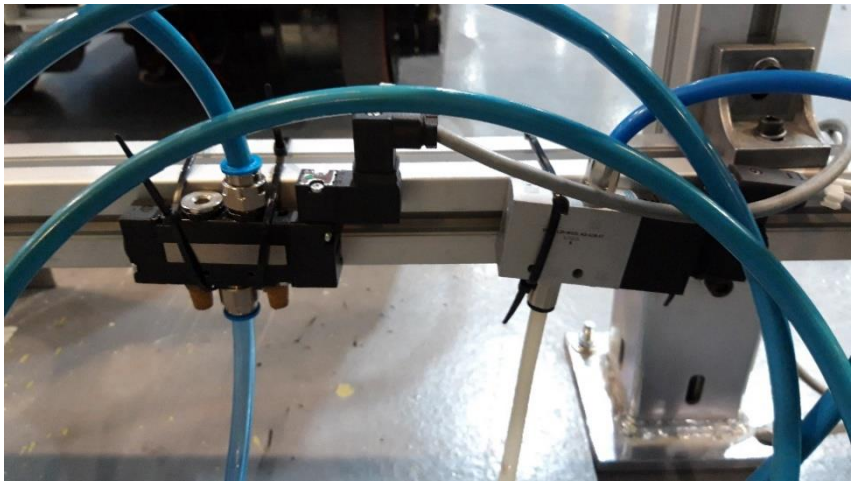


Figure 47: Electro valves for handling the compressed air flow of the drilling unit (left) and the compressed air flow for the docking station (right)

Figure 48: Relay for handling the vacuum system

4.5.2. Working zone modifications

As presented in Figure 19 and Figure 20 the working zones are in different positions. This is due to the differences in the working part, the wing installed in TECNALIA's pilot cell is the opposite of the one of AERNNOVA's pilot cell. For this reason, the working zones have been modified for optimizing spaces and work zones' limitations. Thanks to the flexibility of developed skills, no software modifications are required, only the navigation modules require different positions of the working zones.

4.5.3. Vacuum tube and compressed air tube handling

To avoid interferences or tangles in the air compressed tubes some supports have been added to the profile-based structure (see Figure 49)

Figure 49: Supports for air compressed tubes

Regarding the vacuum tubes, the solution is not as simple because the vacuum tubes have a remarkable weight. If this weight is not compensated or minimized it could affect to the required precise TCP calibration for drilling operation. Lifting and handling devices are expensive, and their need were not identified in the first steps of the project, so a simple and low-cost alternative has been implemented, lot of cable ties tied to each other. This provides a small spring and reduces the supported weight to the robot (Figure 50).

4.5.4 Overcoming safety limitations

For the 3rd review meeting Aeronautic use case demonstrator, the safety zones were configured according to the pilot cell prepared at AERNNOVA's facilities. Even so, due to timing and resource limitations the demo set-up of cables and tubes produces interferences with the configured safety zones and eventually the robot enters in an emergency status when the MRP moves across the working areas. In the Figure 51 the conflicting zones are visualized. The docking station and some tubes of the driller and sanding machine could enter in the safety zone causing not desired emergency stop.

Based on a comment received from project's reviewer, a solution for this issue has been implemented. For having more appropriate approach, it is required to reconfigure the safety zones with an accurate set-up. In the Figure 52, an approximation of the new safety zones is presented.

Figure 50: A set of cable ties tied one to each other for reducing the weight of the vacuum tubes

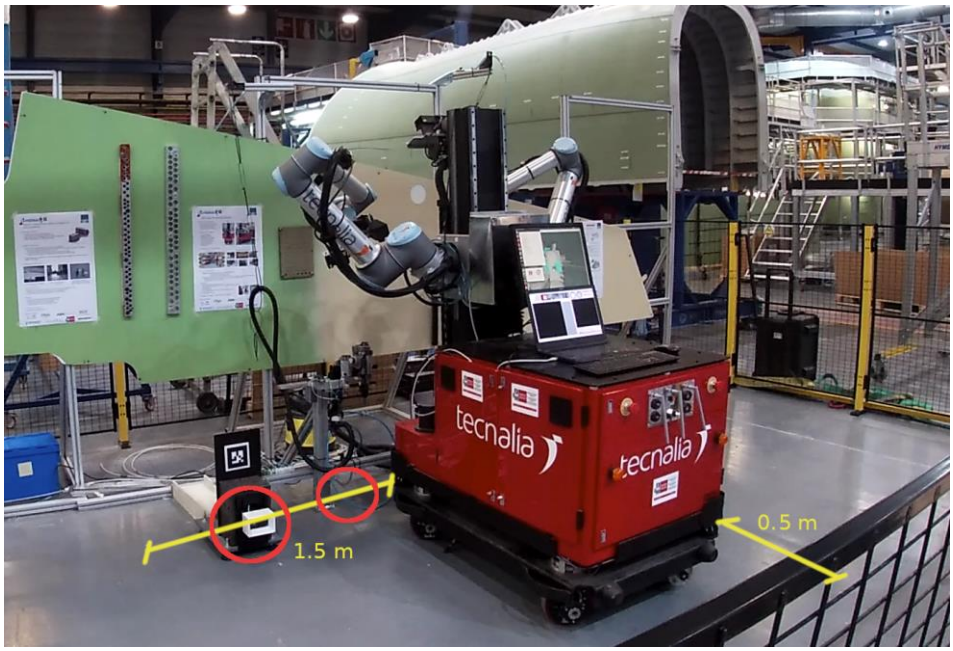


Figure 51: Eventually some cell elements interfere with configured safety zones

As presented in Figure 52, the safety zones at the laterals of the MRP has been modified adding a small angle in order to avoid possible interferences. Besides, in case of industrialization, commercial tube handlers would be installed, reducing unnecessary tubes around. If all the tubes are placed hanged from these devices would not interfere with the laser scanners.

Figure 52: Adjusted safety zones for avoiding interferences

In the following figure the resultant configuration of the safety zones is presented (Figure 53). These are the safety zones defined in the SICK CDS software, combining the front and rear laser scanner sensors' data.

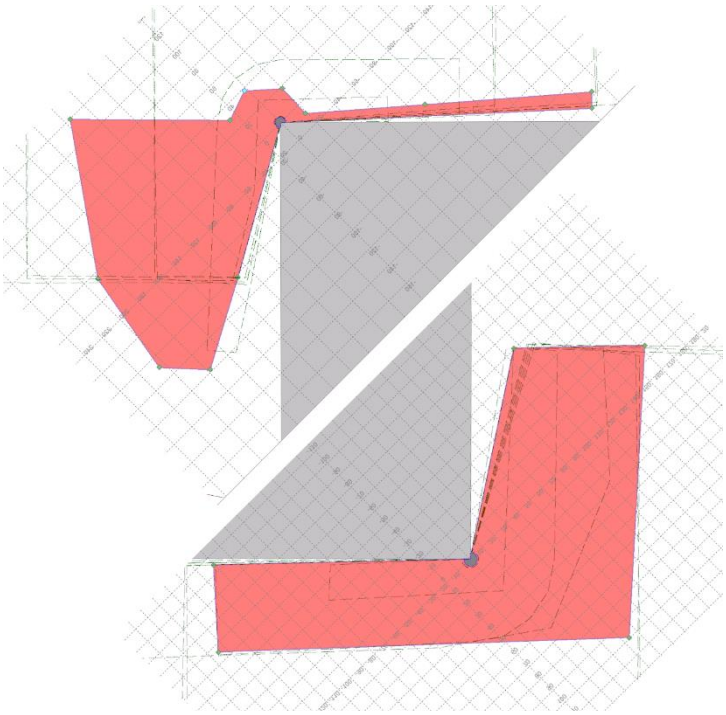


Figure 53: New safety zones for avoiding dock and tube issues

The safety zones configuration as presented in Figure 53 are violated by the tubes of the drilling machine (in Figure 51 at AERNNOVA's facilities conflicts with tubes of the sanding machine). For better understanding, at Figure 55 an upper view of the docking place is presented.

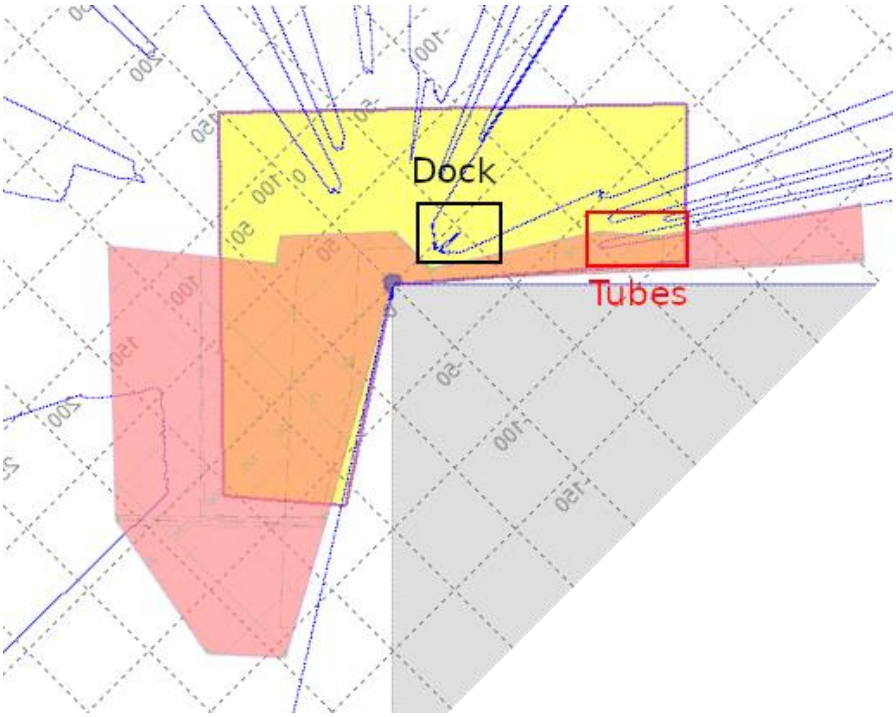


Figure 54: Conflicting areas in previous safety zones

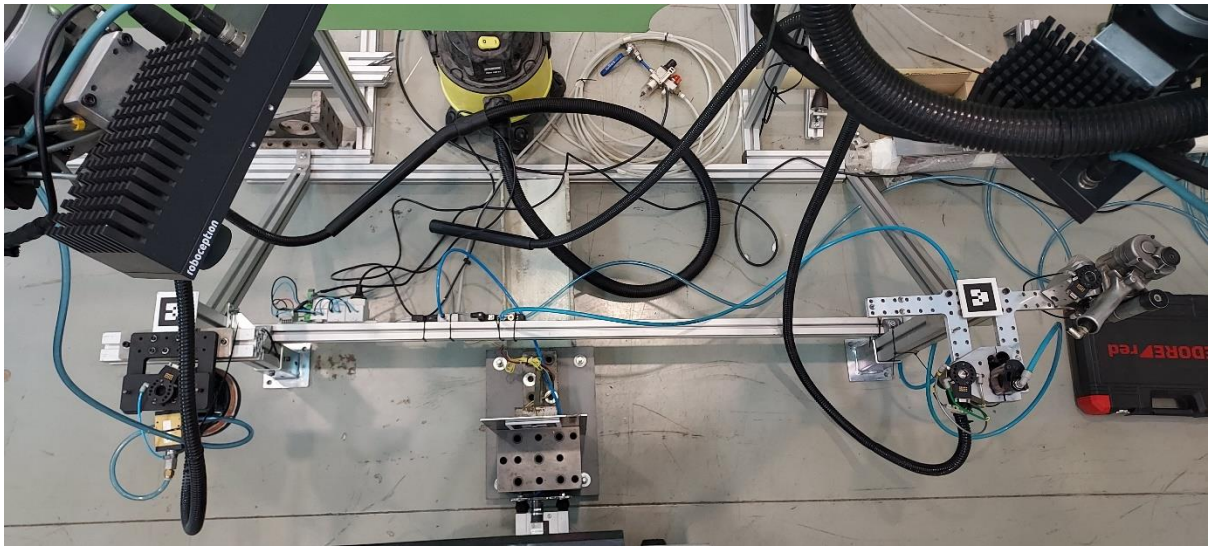


Figure 55: Upper view of the docking place

With the revised safety zones the implemented safety strategy works as expected. The MRP navigates with the surrounding safety zone configured, and when the docking process starts the safety zone in front of the platform is switched to docking safety areas (Figure 53). This allows maintaining a safety zone from the laterals of the MRP and from the rear part, which are the places the operators could come from.

5. CONCLUSIONS

This document provides a description of the hardware and software customization required during the execution of the aeronautics pilot case. It includes also the last version of aeronautics pilot case in AERNNOVA's premises.

In this public deliverable, the final version of all modules' integration inside the aeronautic use case are documented. The aeronautic use case demonstrator has been transferred in end user's premises. As a result of this, THOMAS physical layout of the aeronautic pilot case in AERNNOVA premises have been detailly presented in the above sections.

6. GLOSSARY

WP	Work package
HRI	Human Robot Interaction
MRP	Mobile Robot Platform
GUI	Graphical User Interface
CAD	Computer Aided Design
KPI	Key Performance Indicator
OPS	Open Production Station