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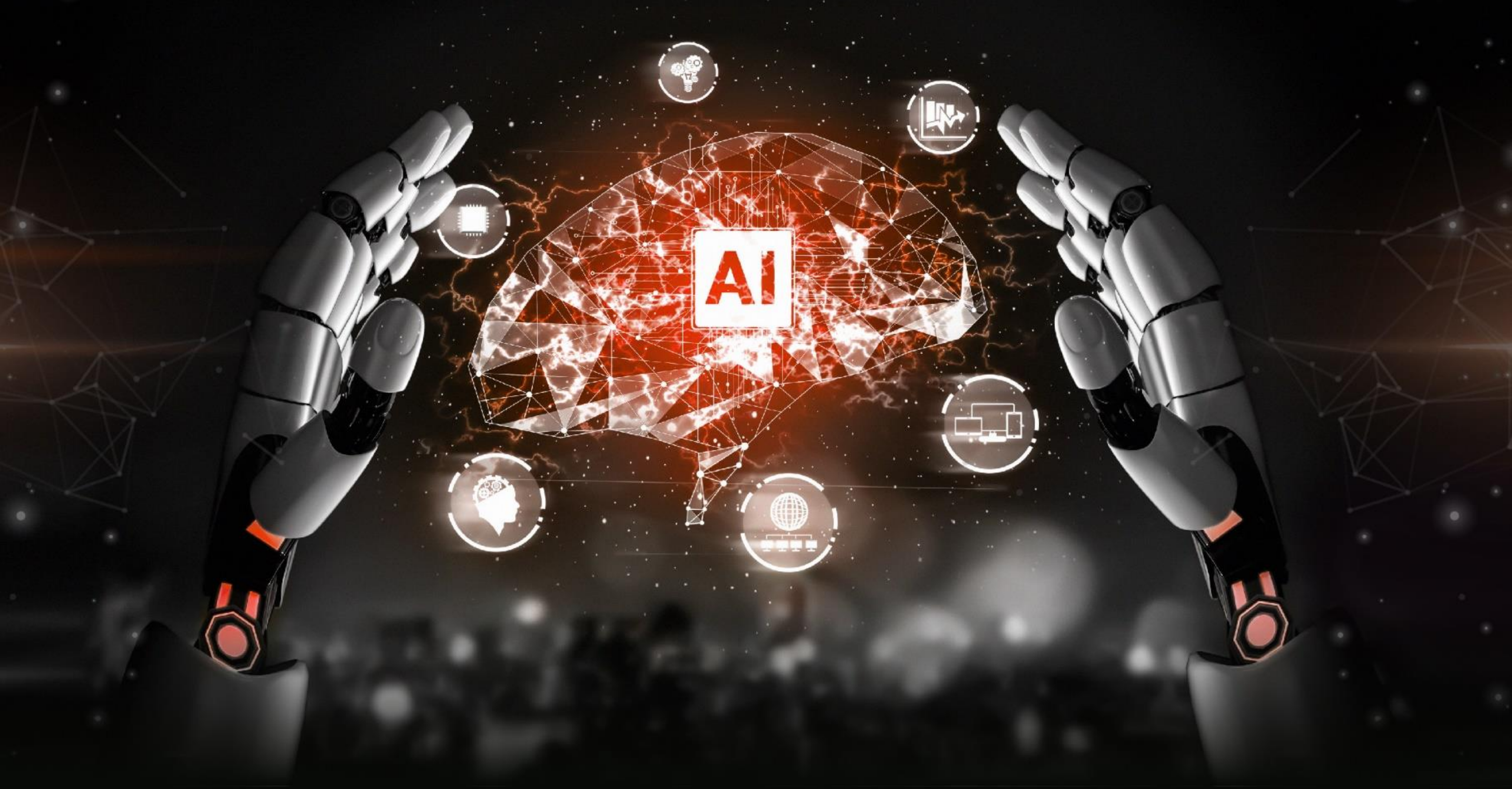
AGIMUS

INNOVATIVE ROBOTICS FOR AGILE PRODUCTION

D6.1 Specification of the industrial pilot case studies



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Disclaimer

Executive Summary

This report was developed within the context of the AGIMUS project, funded by the European Union's Horizon Europe Framework Programme for Research and Innovation 2021-2027, with a view to shed light on the integration of a robotic solution in six different industrial case studies and what risks are identified and how they will be mitigated. To investigate the aforementioned aspects, a detailed analysis of the AGIMUS industrial pilot case studies, has been conducted.

In order to provide a detailed description of the AGIMUS' case studies, a case study definition template is developed. Furthermore, online bi-weekly meetings between technical and industrial pilots were conducted in order to develop the pilot case studies and finally, three shopfloor visits were conducted, one in each of the three pilots. Discussions among the partners took place to better identify the industrial pilot constraints and how to replicate each case study in the testing zone, as well as on the potential end-effectors for these case-studies.

As part of D6.1, a specific assessment was conducted of the technical and non-technical (ethical, legal and societal) risks that piloting activities may raise and a set of mitigation measures to address such risks was provided.

Six industrial pilot case studies are specified, 2 for each pilot, KLEEMANN, AIRBUS and THIMM. In particular, for KLEEMANN the first case study is entitled as "False ceiling assembly" and the second case study is entitled as "Floor covering material gluing and assembly". AIRBUS's case studies are exploring "Holes deburring of predrilled A320Neo pylon sub assembly" and "In orbit assembly process of large-scale reflectors (dummy simplified process)". Finally for THIMM, the case studies are related to "Inserting small plastic pieces into the cardboard" and "Removing cardboard waste from the sheet".

Table of Contents

List of Figures

List of Tables

1. Introduction

1.1 AGIMUS project overview

AGIMUS (Next generation of AI-powered robotics for agile production) aims to deliver an open-source breakthrough innovation in AI-powered agile production, introducing solutions that push the limits of perception, planning, and control in robotics, enabling general-purpose robots to be quick to setup, autonomous and to easily adapt to changes in the manufacturing process.

To achieve such agile production, AGIMUS leverages on cutting-edge technologies and goes beyond the state-of-the-art to equip current mobile manipulators with a combination of (i) an advanced task and motion planner that can learn from online available video demonstrations; (ii) optimal control policies obtained from advances in reinforcement learning based on efficient differentiable physics simulations of the manufacturing process; as well as (iii) advanced perception algorithms able to handle objects and situations unseen during initial training. Along the way, optimization of energy efficiency and the use of 5G technology will support further pushing the limits of autonomy.

The AGIMUS solutions and their impact will be demonstrated and thoroughly stress-tested in 3 testing zones, as well as 3 industrial pilots in Europe, under numerous diverse real-world case studies and scenarios (different tools, environments, processes, etc.). In every step, and from the very beginning, AGIMUS will go beyond current norms and involve a wide range of stakeholders, starting from the production line itself, to identify the essential ethical-by-design principles and guidelines that can maximise acceptance and impact.

To this end, the consortium of AGIMUS brings together a complementary and interdisciplinary group of 9 partners across 4 different countries within the EU. This deliverable focuses on the specification of each case study, identifying the specific steps that the TIAGo should achieve, what components must have and what processes are expected to be automated, in order to accomplish its tasks and more specifically to demonstrate the versatility and effectiveness of the AGIMUS framework for agile production.

D6.1 specifies the pilots' approach to the case studies, which is expected to be the basis for the development of a comprehensive requirements list, that will assist in the development of a prototype system, which is aimed to be used in each case study by making the appropriate modifications.

1.2 Purpose

This deliverable lays the groundwork for specifying the industrial pilot case studies by connecting the robotic skills to each case study and identifying potential risks. More specifically, by specifying AGIMUS' case studies, the deliverable aims to identify the key issues regarding the shopfloor requirements, for enabling the deployment and analyse the case studies using relevant methodology, for example on-site visits to each industrial pilot, systematic case study design and simplify processes according to industrial scenarios. Last but not least, the purpose of this deliverable is to identify the existing and future risks that may hinder the deployment of the AGIMUS' solutions, along with the mitigation actions that should be taken into account to reduce the impact. Finally, this deliverable presents the results and the next steps.

1.3 Content and structure

The production of this deliverable is the outcome of Task 6.1 Industrial Pilot Case studies Design and Planning. The deliverable's structure is presented below:

- In Chapter 1 the introduction of this deliverable is presented.
- In Chapter 2, each pilot case study is described in detail.
- Chapter 3 analyses the methodological approach
- In Chapter 4, the results of this deliverable are presented, including the connection of case studies with the robotic skills and the identification of the risks
- Chapter 5 comprises the conclusions drawn from the study and outlines the subsequent steps to be taken.

This document relates to several key deliverables within the project framework:

- **Deliverable D1.1, specifically in Section 3.3**, outlines the identification of needs, challenges, barriers, drivers, and enablers for agile production pertinent to this project's scope.
- In **Deliverable D1.1, Section 3.4** details the identification of crucial production indicators such as production time, defects, downtime, workspace, and waste. These indicators, along with collected values from each case study, serve as foundational inputs for Deliverable 6.4. These metrics will be closely monitored throughout the development of solutions in the Testing Zones and their subsequent deployment in the Industrial Pilots during T6.2.
- **Deliverable D5.1, within Section 2.4**, specifies the Robotic Skills earmarked for testing in the experiments of Work Package 5 (WP5) and the case studies of Work Package 6 (WP6). Each Robotic Skill is defined by unique acceptance criteria and performance metrics, which will be tracked across the pertinent case studies.
- **Deliverable D6.4** shall introduce the evaluation methodology for the use cases, incorporating metrics to oversee the implementation of AGIMUS technologies in the industrial pilots. These metrics cover both technical and non-technical aspects and are derived from Work Packages 2 to 4 (core technologies), WP5 (experiments), and also from Deliverable D6.1 (industrial pilots).

2. Description of the industrial pilot case studies

In this section, the three industrial pilot sites of AGIMUS project i.e. (i) the aircraft and satellite manufacturing (AIRBUS), (ii) the lift manufacturing (KLEEMANN) and (iii) the packaging manufacturing (THIMM), are described in order to provide a better understanding of the impact of the developed solutions in real world settings. The industrial needs of AGIMUS, will be presented in 2 different use cases in each of the three pilots (6 in total):

2.1 Aircraft and satellite manufacturing, France

Airbus manufactures among other products, civil aircrafts and satellites. Both of these products are produced in small batches and often require adaptation between a unit and the following one. Several attempts to introduce robots in the final assembly of these products have failed because of the high cost and the lack of flexibility. To assess the relevance of AGIMUS project solutions, we will focus on two pilots: deburring of pre-drilled holes on aircraft pylons (CS1.1) and in orbit assembly process of large-scale reflectors (CS1.2).

2.2 Lift manufacturing, Greece

KLEEMANN specializes in high quality solutions, where precision is required on every step of the production line. The key products of KLEEMANN include a dimensional range of fully-customised and standardized elevators, that meet every project' s and customer's demands. Every product has different specifications and dimensions as well. While KLEEMANN is a trusted manufacturer, and provides reliable products and services, with fast production times, in some occasions some tasks could be performed faster and with improved quality by a robot. Two of these occasions are identified. More specifically, the pilot will focus on the false ceiling assembly (CS2.1), as well as on the floor covering material gluing and assembly (CS2.2) where accuracy and quality are mandatory.

2.3 Packaging manufacturing, Czech Republic

THIMM pack'n'display shopfloor, located in Všetaty, Czech Republic, offers the best solution for the packaging and display of merchandise. With customized packaging, individual display concepts made of corrugated cardboard, and the most modern digital printing technology, THIMM develops the best solution for the given products. The highly customized packaging leads to a small-batch production currently handled manually. Two sub-processes of a small-batch production are identified for the potential automation via the AGIMUS framework: inserting small plastic pieces into the cardboard (CS3.1) and removing cardboard waste from the sheet (CS3.2). This second THIMM's case study, originally named "Gluing cardboard sides together", has been changed to "Removing cardboard waste from the sheet". This change was made because the specialized gluing machine for the cardboard gluing process is already used on the THIMM shopfloor. Contrary to that, cardboard waste removal is performed solely by human operators, nowadays.

3. Methodology

In order to provide a detailed description of the AGIMUS' case studies, a case study definition template is developed. Furthermore, online meetings between technical and industrial partners were conducted every two weeks and finally, three shopfloor visits were conducted, one in each of the three pilots.

3.1 Case study definition template

A case study includes a list of steps, typically defining interactions between the operators and the robot in order to achieve a goal. The involved operators can be equipped with some tools or external systems. A case study template is designed by WP6 partners in the context of Task 6.1: Industrial Pilot Case studies Design and Planning. This template is used for the AGIMUS case study definition and each case is represented as a sequence of simple steps from the pilot's perspective. This template serves as a tool for identifying the process steps that can be handled by TIAGo.

Table 1 Case study template

Step	Description	Operator	TIAGo AGIMUS Robot	Indicative photo
1				
2				

3.2 WP6 meetings and visits

3.2.1 Online bi-weekly meetings

One key aspect of the methodology that was followed in D6.1, is the organisation of bi-weekly meetings, in order to examine the context of case studies in more detail and also to review the progress of the WP6. In close collaboration with technical partners, the end-users were involved in the process of requirements' connection to case studies specification, to enable and strengthen the clarity and accuracy of the developed solutions and also to provide assistance in case of changes, in safety issues and in future risks as well.

3.2.2 Shopfloor visits

Apart from the online bi-weekly meetings, shopfloor visits and workshops have assisted in the development and specification of the industrial pilot case-studies. The three industrial pilot partners, AIRBUS, KLEEMANN and THIMM, have presented the initial set of case studies' specifications to the technical partners for developing simulation scenarios related to the TIAGo robot. This gives the ability to mimic what is performed in simulation with the real robot that will be deployed in the shopfloor. After the comments from technical partners, the case studies were finalized and communicated to the consortium in detail.

The consortium shopfloor visit to the THIMM premises took place on the 25th and 26th of April, 2023, during the 2nd physical AGIMUS project meeting in Prague. The visit started with an overview of the fully automatized parts of the factory; more specifically, the following items were presented: machines for the production of corrugated cardboard, automatic systems of transportation of work in progress, corrugated cardboard processing machines, robotic palletizers, flexo and digital printing machines, packaging technology, and the overall method of making corrugated board. The visit continued with a small-batch production section where the processes currently handled by human operators were analyzed. The analyses led to the case studies definitions described in the following sections. Another visit was performed between CTU and THIMM on the 25th of January, 2024, to specify the use cases in more detail.

The consortium shopfloor visit to Airbus premises took place on the 5th of July 2023. The visit started by a visit of the factory Saint-Eloi in Toulouse where a person from Airbus gave an overview of the various operations conducted in the factory, focussing on manual operations that could be automatized. Those operations mainly fall into 3 categories: logistics, machine feeding and machining. The presentation of deburring operations was of particular interest. Most of them are performed by immersing parts to process in a vibrating container filled with small tetrahedrical rocks, but for some parts, deburring of pre-drilled holes is performed by operators with hand-held tools. Automatizing the latter operation is the topic of one case study (CS1.1).

The final shopfloor meeting occurred on February 20, 2024, at KLEEMANN's facilities. The agenda included a comprehensive tour across various factory buildings to understand the diverse manufacturing processes involved in elevator production and to observe the site's logistics. The itinerary also featured visits to the test tower, showroom, and a training area designed for global distributors. Additionally, two presentations focused on the CS2.1 and CS2.2 pilots were conducted, which included direct interactions with the operators. This was followed by discussions among partners aimed at delineating the constraints of the industrial pilot and strategies for replicating these conditions in the Inria Testing Zone, along with deliberations on suitable end-effectors for the case studies.

4. Results

4.1 Specification of industrial pilots

In order to better understand the current status, expected improvements and risks of actual real-world industrial adopters of the AGIMUS solution and uncover further aspects of agile production, more detailed information regarding AGIMUS' industrial pilot case studies were requested from the industrial partners, aligned with activities under T6.1, which are expected to further elaborate on the industrial pilot case studies.

4.1.1 Specification of the Aircraft & Satellite manufacturing pilot

4.1.1.1 CS1.1 - Holes deburring of predrilled A320Neo pylon sub assembly

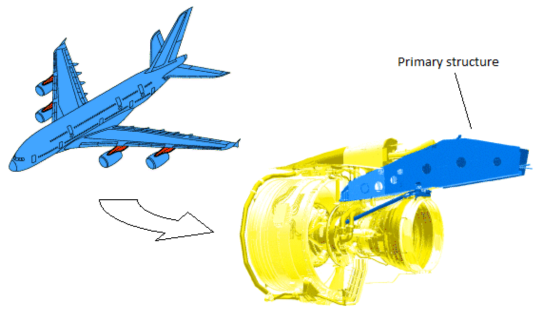


Figure 1 Pylon primary structure

Figure 1 Deburring process with retractable cutting tools (to perform inner and outer side of a part)

Deburring is performed on each drilled holes, for inner and outer side of a part (see **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**) before any fastening process (not described here). It is either done by 1 to 3 "blue collar" operators or using machines (sharing same space or same task).

It should be noted that the elementary parts used in the assembly and considered for this use cases are fairly expensive (titanium or carbon fiber parts following a costly manufacturing process).

Furthermore, these oversized parts are not directly manageable in lab conditions. Therefore, dummy parts are preferred instead to demonstrate the capabilities of the pilot (see **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**). Design of dummy parts to be used are still to be defined accordingly to robot travel limits and capabilities, with regards to previous performed experiments. The Operator and the Tiago robot are doing exactly the same tasks, on a different location of the part. However, sharing space could be either operator on one side of the part and robot on the other, or robot and operator and robot on the same side, but in that case, a safety geofencing following strictly the ISO 10218 and ISO 13482 will be needed.

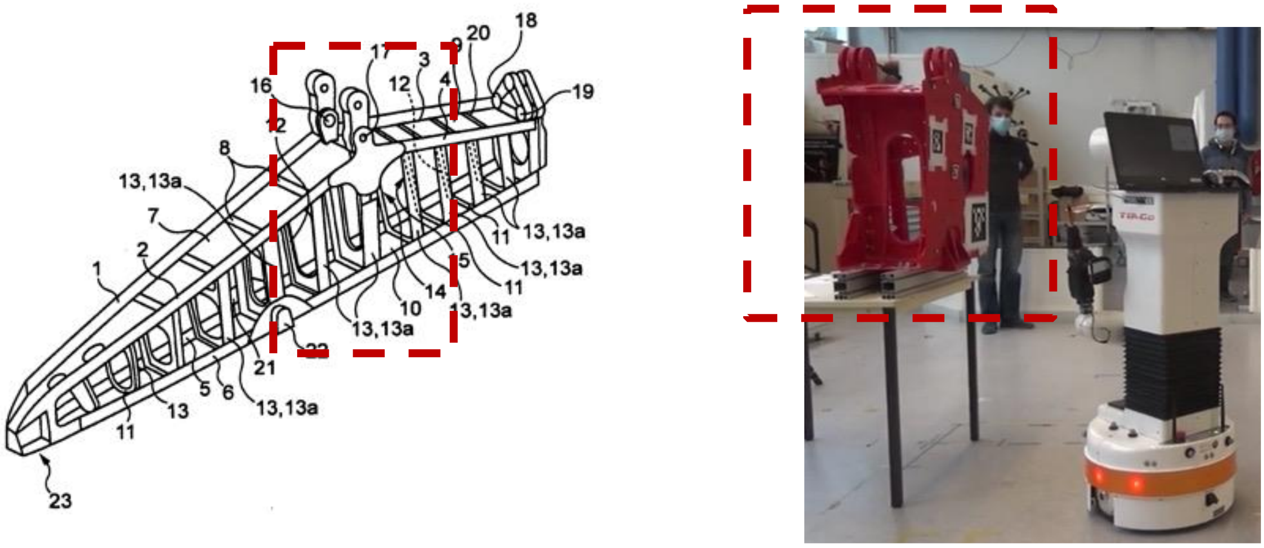
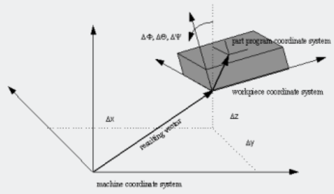
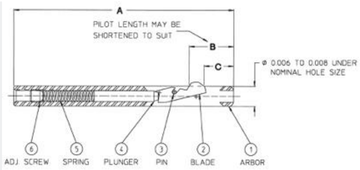
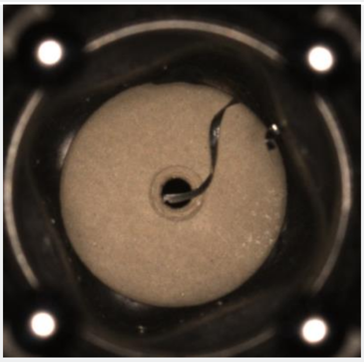
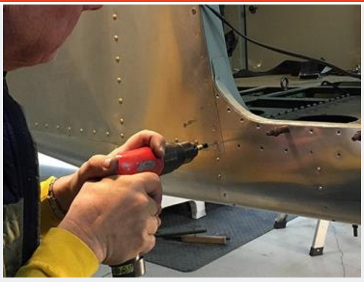


Figure 2 Simplified setup for pylon deburring

Table 2 Holes deburring of predrilled A320Neo pylon sub assembly

Step	Description	Operator	TIAGo AGIMUS Robot	Indicative photo
1	Position the jigs in place (parts inserted in the jigs)	Control the jigs through cabinet or remote command		 (pylon is fully assembled on that photo)
1bis			Datum definition after positioning (for automatic deburring)	
2	Downselect and pick the “right tool” versus the sets of holes to deburr	Pick the correct manual tool (deburring/cutting tools are already installed in handheld tools and calibrated upfront)	Mount the correct end effector (deburring/cutting tools are already installed in end effector and calibrated upfront)	
3	Partition the subassembly in subsequent tasks (for example, by panels or by subpart of panels)	Select areas of part to be processed	(robot is used as companion or geofenced, performing the same action)	
4a	Position in front of hole accurately (centered on hole with +/-0.1mm relative positioning to perceived hole center, with local normal to surface at 0.2° of relative sensed normality)		(robot is used as companion or geofenced, performing the same action)	

Step	Description	Operator	TIAGo AGIMUS Robot	Indicative photo
4b	If hole not already processed (by previous operator, machines, …) Deburr (with local normality compensation)	Deburr (ie manual insertion of cutting tools in holes)	(robot is used as companion or geofenced, performing the same action)	
	Redo loop 2-3-4 until full completion			
5	Clean the burrs	Vacuum of the dust / remaining burrs	Might be combined at each hole in 4b with appropriate end effector	
6	Perform final visual check (all holes deburred successfully)	Perform quality visual check	Robot could perform too this action with appropriate resolution cam + computer vision analysis	

4.1.1.2 CS1.2 - In orbit assembly process of large scale reflectors (dummy simplified process)

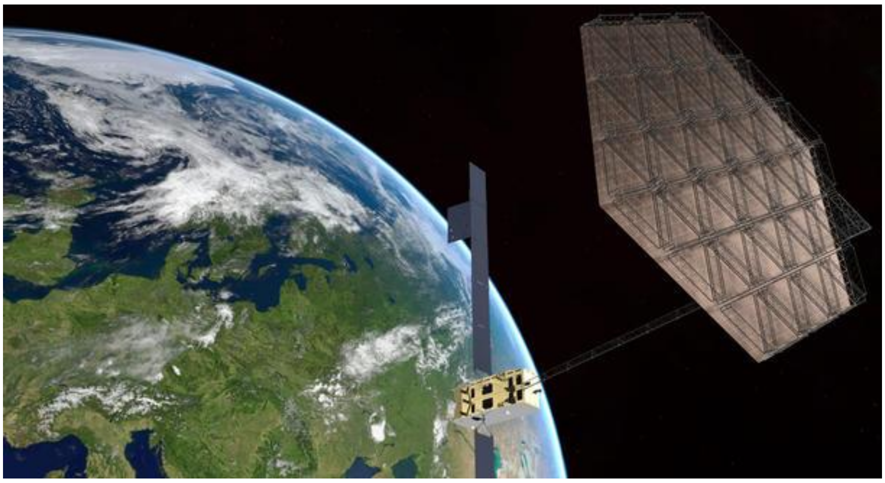


Figure 3 Large antenna reflector in low orbit (concept)

Instead of launching large in-orbit systems (through deployable mechanism once in orbit, see Figure 4, investigations are oriented towards performing the assembly of the structure directly in orbit. It is also covering in orbit repairs (i.e. replacing parts).

In order to ensure assembly within tolerances, uncertainty propagation must be managed while mounting each element sequentially (using visual servoing and global position error in the process, see **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**. Local misalignment can introduce insertion of "unmount tasks" into the scheduled plan (see table below, task 6). This enables to mount them again with less assembly error "budget" which allows global fitting of the assembly tolerance.

Here operators could be astronauts (especially when considering repairs). Therefore, in this case study, the objective would be to suppress any manual assembly tasks or at least to reduce it drastically. In other words, the process should be manageable by either human operator or robot operator.

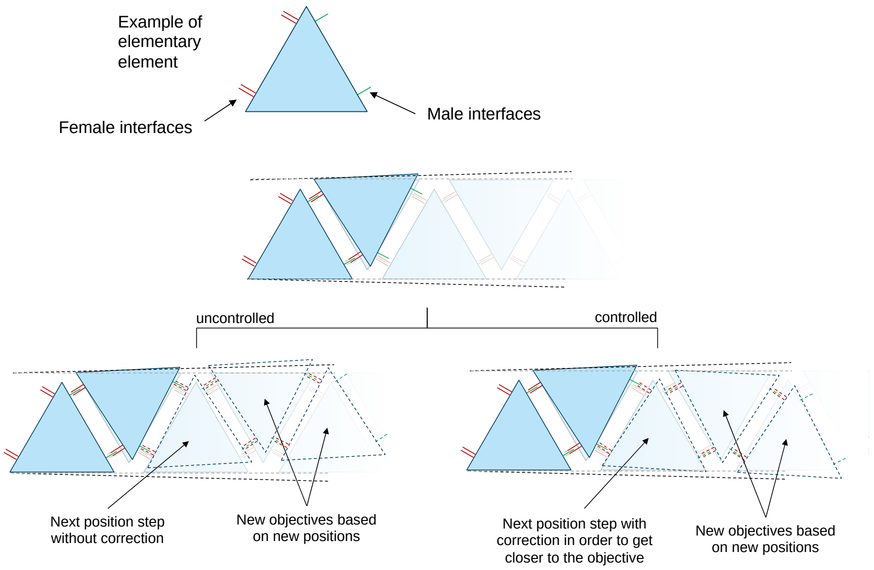


Figure 4 Deviation problem during assembly process

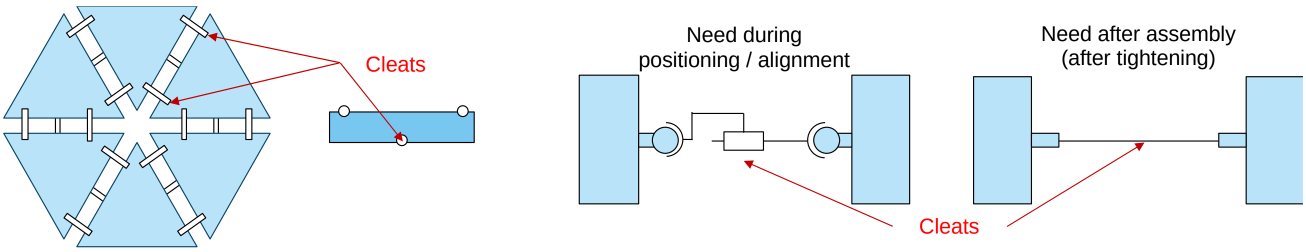
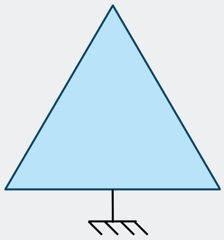
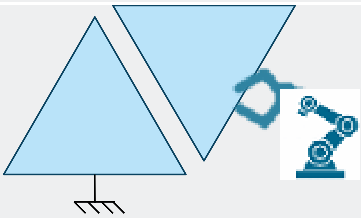
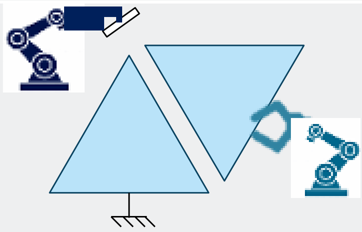
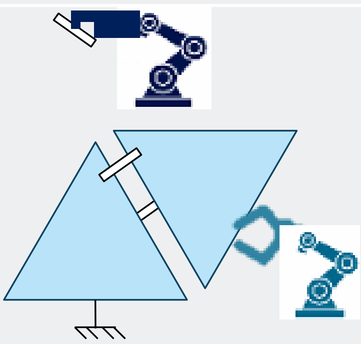
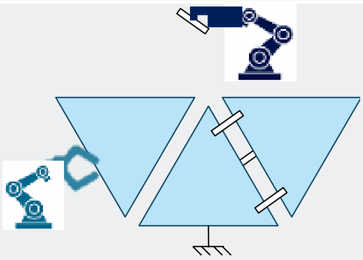


Figure 5 How to perform assembly with cleats

Table 3 In orbit assembly process of large scale reflectors (dummy simplified process)

Step	Description	Operator	TIAGo AGIMUS Robot	Indicative photo
1	Lock 1st element into the positioner jig	See Remark below	See Remark below	
2	Position element n with arm 1 within tolerance and lock it in position within tolerance		See Remark below	
3	Position cleat c with arm2, between element n and n-1. Lock it (using tightening process)	See Remark below	See Remark below	
4	Measure “real” position of element n and compare with tolerance		Typically, we use a photogrammetric measurement end effector (in Agimus setup we will fudge the system measurement with results direct insertion	
	If cleat c is installed within tolerance Loop 3 and 4 for 2 more cleats (upper first then backside)		See Remark below	
5	compute generated position error (incl uncertainties) of all	See Remark below- if performed by	See Remark below	

Step	Description	Operator	TIAGo AGIMUS Robot	Indicative photo
	already assembled elements	human operator, it is the ground team processing the data		
6	If general error is still within general assembly tolerance, Loop 2 to 5 for next element Else INSERT a task: Unmount cleats of element n and go back to 2, with error budget reduced for positioning	See Remark below	See Remark below	
7	Unlock element 1, maintained by a jig	See Remark below	See Remark below	
8	Redo same process (1-6) and assemble on other ring of elements …	See Remark below	See Remark below	

Remarks:

Here operators could be astronauts (especially when considering repairs). Therefore, in this use case, the objective would be to suppress any manual assembly tasks or at least to reduce it drastically. In other words, the process should be manageable by either human operator or robot operator.

- Any action in the task table above shall be designed to be managed by the TIAGo Agimus
- When considering Arm1 / Arm2 in some actions, it can be either using a dual arm robot, or 2 distinct robots (depending on robot abailability)
- The human operator will be considered in real use case for corrective actions on demand only

- Alternatively, some specific tasks sharing (at mission level) between robot and human operators are considered, but they are outside of Agimus project.

4.1.2 Specification of the Lift manufacturing pilot

4.1.2.1 CS2.1 - False ceiling assembly

In this case study, currently two operators pick the false ceiling and position it on the working surface. Afterwards the operator identifies and marks the position of the placement of the reinforcement parts. The operator spreads the glue uniformly and positions the reinforcement parts to the aforementioned positions. Finally, the operator presses the parts in order to remove possible bubbles of the glue and inspects the glued products.

With this case study, the processes of handling the false ceiling and reinforcement parts, will be covered. TIAGo AGIMUS robot helps the operators to transport, mark, apply glue, place and press parts with the contribution of an automatic gluing machine.

With this case study, the operators want to safely share the workspace with the robot. Due to the variety of shapes and sizes of the ceiling components, Robot's versatility and accuracy of the glue disposal are required. The key goal of this case study is to reduce the exposure of the employees to chemical fumes and reduce the chemical management by 90%. Moreover, a glue disposal quality and quantity improvement by 30% and an increased productivity by 15%, as the glue can be dispensed homogeneously along a part.

In order to implement this case study, the steps in the template below will be followed:

Initially two operators pick the false ceiling and position it on the working surface. The robot identifies the appropriate positions where the reinforcement parts will be glued. It then spreads glue in the aforementioned spots, positions and presses the reinforcement parts to these spots. Finally, the operator, as well as the robot, inspect the glued parts.

Table 4 False ceiling assembly -KLEEMANN

Step	Description	Operator	TIAGo AGIMUS Robot	Indicative photo
1	Picking of the false ceiling	The operators pick the false ceiling		
2	Positioning of the false ceiling on the working surface	The operators position the false ceiling on the working surface		

Step	Description	Operator	TIAGo AGIMUS Robot	Indicative photo
3	Identifying the positions of the reinforcement parts		The robot identifies the positions of the placement of the reinforcement parts	
4	Glue spreading		The robot spreads the glue to the identified positions uniformly	
5	Positioning and pressing the reinforcement parts		The robot is positions and presses the reinforcement parts to the identified spots	
6	Visual Inspection	The operator inspects the glued parts	The robot visually inspects the right positions of the glued parts	

Technical characteristics and dimensions

The type of glue that is applied for gluing the reinforcements of the ceiling is: 3M VHB Tape Universal Primer UV and the height of the workbench varies from 90cm to 95cm (it depends on the workbench).

Figure 6 Type of glue for the ceiling

The dimensional range for the ceiling and its reinforcements are the following:

- Min 600mm*600mm, reinforcement part 600mm*140mm
- Max 1400mm*1600mm, reinforcement part 1600mm*140mm

- 15mm distance from each side (see photo below)

Figure 7 Pointing the gap between reinforcement part and the edge of ceiling

4.1.2.2 CS2.2 - Floor covering material gluing and assembly

The second KLEEMANN's case study, originally named "Cabin side parts gluing and assembly", has been renamed "Floor covering material gluing and assembly". This change was made because the process for cabin side parts was decided to start being already automated. The requirements for gluing and assembling either the cabin side parts or the floor covering material are essentially the same.

In this case study, currently two operators cut the floor's material in the appropriate length, position the wood on the workstation and position the floor's material on the wood. Afterwards, the operator spreads the glue uniformly in the floor's material and leaves it in a separate place in order to dry. The operator spreads glue in the wood uniformly, as well. When it dries the operators place the dried floor's material on the wood. Thereafter, the operator cuts the exceeding material. Finally, the operator presses the floor's material in the wood, in order to remove possible bubbles of the glue and inspects the glued products.

With this case study, the processes of handling the floor, will be covered. TIAGo AGIMUS robot helps the operators to apply glue, place and press parts with the contribution of an automatic gluing machine.

With this case study, the operators want to safely share the workspace with the robot. Due to the variety of lengths of floor's material, robot's versatility and accuracy of the glue disposal are required. The key goal of this case study is to reduce the exposure of the employees to chemical fumes by 90%. Moreover, a glue disposal quality and an increased production rate by 20% and a decreased stress by 20%, as the creation of a production line without gaps and manual handling of materials offer a significance assistance to the operators.

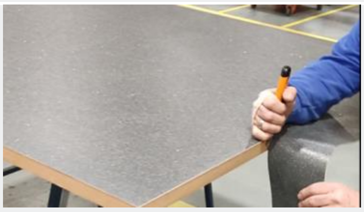
In order to implement this case study, the steps in the below template will be followed:

Initially two operators cut the floor's material in the appropriate length, position the wood on the workstation and position the floor's material on the wood. Afterwards, the TIAGo AGIMUS Robot spreads the glue uniformly on the floor's material and leaves it in a separate place in order to dry.

TIAGo AGIMUS Robot spreads glue on the wood uniformly, as well. When it dries the operators place the dried floor's material on the wood. Thereafter, the operator cuts the exceeding material. Finally, TIAGo AGIMUS Robot presses the floor's material on the wood and the operator inspects the glued products.

Table 5 Cabin side parts gluing and assembly- KLEEMANN

Step	Description	Operator	TIAGo AGIMUS Robot	Indicative photo
1	Cutting the material of the floor to the appropriate length	The operators cut the material of the floor		
2	Positioning of the wood on the workstation	The operators position the wood on the workstation		
3	Positioning of the floor's material on the wood	The operators position the floor's material on the wood upside down		
4	Glue spreading	The operator spreads the glue on the floor's material		
5	Placing the glued floor's material in a separate place	The operators place the floor's material for drying		
6	Glue spreading	The operator spreads the glue on the floor's material		

Step	Description	Operator	TIAGo AGIMUS Robot	Indicative photo
7	Positioning the floor's material	The operators place the dried floor's material on the wood		
8	Cutting the exceeded material	The operator cuts the floor's exceeding material		
9	Pressing		The robot presses the floor's material on the wood	
10	Visual Inspection	The operator inspects the glued parts		

Technical characteristics and dimensions

The type of the glue for floor material (MDF) is Neostick 588 (High Quality Rubber Adhesive) and the height of the workbench varies from 90cm to 95cm (it depends on the workbench).

Figure 8 The glue for the floor material (MDF)

The dimensional range for the floor (MDF) is:

- Min 600mm*600mm
- Max 1600mm*1100mm

4.1.3 Specification of the Packaging manufacturing pilot

Unlike the Aircraft & Satellite and Lift manufacturing pilot, the Packaging Manufacturing Pilot will not use the TIAGO AGIMUS Robot for the implementation. Instead, KUKA robots with capabilities similar to TIAGO AGIMUS robots will be used. This will allow us to deploy and test AGIMUS software architecture to other platforms already available in the CIIRC Testbed at CTU in Prague.

4.1.3.1 CS3.1 – Inserting small plastic pieces into the cardboard

In this case study, currently, a human operator inserts a set of plastic pieces into the cardboard sheet. Holes for the plastic pieces are prefabricated and accurate manipulation is required to insert the piece into the hole. The fine manipulation challenge makes it a task suitable for robotic automation.

This case study analyze the process of inserting plastic pieces into the prefabricated holes. Kuka collaborative robot will localize the plastic piece from a set of pieces, pick it, and use combined haptic and vision feedback to insert the piece into the hole accurately. The shape and texture of the pieces are always the same. On the other hand, the shapes and textures of the cardboard sheets vary, and the robot equipped with AGIMUS software should adapt to these changing scenarios. The cardboard sheets' dimensions will vary from a few to tens of centimetres in such a way that they fit into the robot workspace. The key steps of the process are shown in Tab. 5.

Within this case study, human operators will share the workspace with the robot as the manipulation of the cardboard sheets will be managed by operators. The safety of the operator needs to be ensured by the AGIMUS software. The key goal of this case study is to help humans with fine manipulation tasks, which might be challenging to perform consistently for an extended period of time. It is expected that uninterrupted robotic manipulation will lead to an increase in productivity of this task by 15% compared to human operators.

Challenges for the robotic manipulator include (i) operators might disturb the process, and their safety must be enforced, (ii) sensitive product parts that the robot can damage, (iii) high accuracy in bin picking of small pieces, and (iv) handling diverse large, light, and flexible cardboards.

Table 6 Inserting small plastic pieces into the cardboard

Step	Description	Operator	TIAGo AGIMUS Robot	Indicative photo
1	Picking the cardboard sheet from the stack and placing it into the robot's workspace.	The operator picks and places the sheet manually.		
2	Localizing the cardboard sheet and holes.		The robot localizes the poses of the sheet and holes with a vision.	

Step	Description	Operator	TIAGo AGIMUS Robot	Indicative photo
3	Localize the plastic piece.		The robot localizes the poses of the plastic pieces with a vision.	
4	Picking the plastic piece.		The robot grasps the plastic piece.	
5	Inserting plastic pieces into the hole.		The robot uses combined vision and haptic feedback to insert the piece into the hole.	
6	Removing the cardboard from the robot's workspace	The operator removes the cardboard from the workspace after all holes are filled.		

4.1.3.2 CS3.2 – Removing cardboard waste from the sheet

While producing the cardboard boxes or displays, it is necessary to prefabricate holes in them, e.g., for plastic piece insertion analyzed in CS3.1. The contour of the hole is automatically cut with a laser, and in ideal conditions, the inside of the hole (i.e., the cardboard waste) is removed by gravity after the cut. However, sometimes, this is not a case affecting the quality of the final product. Therefore, the human operator inspects all cardboard sheets and removes the cardboard waste if stacked in the sheet. The operator uses a tool to remove the waste from a few sheets of the same type simultaneously. This case study aims to visually analyze and automate cardboard waste removal with AGIMUS software control architecture.

This second THIMM's case study, originally named "Gluing cardboard sides together", has been changed to "Removing cardboard waste from the sheet". This change was made because the specialized gluing machine for the cardboard gluing process is already used on the THIMM shopfloor. Contrary to that, cardboard waste removal is performed solely by human operators, nowadays.

This case study will analyze the process of removing cardboard waste from pre-cutted holes. Kuka robot will localize the cardboard sheet in its workspace and identify the waste from the drawing of the expected sheet shape. A tool manipulated by the robot will be used to remove the identified waste. Automatic visual quality inspection will confirm that all the waste has been removed successfully. The shape, texture, and number of prefabricated holes vary; the robot equipped with AGIMUS software should adapt to these changing scenarios. The cardboard sheets' dimensions will vary from a few to tens of centimetres in such a way that they fit into the robot workspace. The key steps of the process are shown in Table 7.

The key goal of this case study is to help human operators with quality inspection and waste removal. Task automation with no time loss due to robot safety enforcement is expected for this case study. Challenges for the robotic manipulator include (i) handling sensitive product parts that the robot can damage, (ii) handling diverse large, light, and flexible cardboards with varying shapes and textures, and (iii) task automation with no time loss.

Table 7 Key steps for CS3.2 - Removing cardboard waste from the sheet.

Step	Description	Operator	TIAGo AGIMUS Robot	Indicative photo
1	Bringing the pallet to the robot workspace.	Operator brings the pallet to the robot workspace.		
2	Picking the cardboard sheet from the stack and placing it into the robot's workspace.		The robot picks and places the sheet automatically.	
3	Localizing the cardboard sheet and the waste.		The robot uses a camera to localize the poses of the sheet	

Step	Description	Operator	TIAGo AGIMUS Robot	Indicative photo
			and the waste that needs to be removed.	
4	Removing the waste.		The robot automatically removes the waste from the sheet by manipulating the tool.	
5	Quality inspection.		The robot uses a camera to inspect that all waste was removed.	
6	Placing processed sheet on the pallet.		The robot places the sheet on the pallet automatically.	
7	Moving pallet to the next stage.	The operator moves the pallet outside of the robot workspace.		

4.2 Connecting robotic skills with testing zones and case studies

The D5.1 “Specification of the AGIMUS Testing Zones, Robots and Skills”, outlines six robotic skills crucial for the development and operation of robotic systems:

- **RS1** focuses on the robot's ability to estimate the 6D poses of known objects from RGB(-D) images, facilitating pose estimation and scene reconstruction.
- **RS2** involves planning the robotic arm's trajectory based on the detected object's 6D pose, aiming to smoothly transition the robot from its initial position to the object's location.
- **RS3** emphasizes planning that takes the surrounding scene into account, specifically aiming to efficiently pick objects from various positions within a box.
- **RS4** assesses the feasibility and adequacy of trajectories generated by AGIMUS developments, ensuring they comply with machine directives and are smooth and efficient.
- **RS5** is concerned with the low-level control of the robotic arm, particularly its response to external perturbations through torque profiles and environmental impact quantification.
- **RS6** addresses the challenge of estimating the 6D poses of large objects from RGB(-D) images that may not fully fit within the image frame.

These skills collectively enhance robotic systems' efficiency, adaptability, and safety in performing complex tasks and interactions within their operating environments.

A reminder of which robotic skill will be tested and where is provided in Table 8.

Table 8 Mapping of Robotic skills with experiments and case-studies of AGIMUS where they apply

	Testing Zone			Case Study					
	LAAS-CNRS	CIIRC	INRIA	AIRBUS		KLEEMANN		THIMM	
				CS1.1	CS1.2	CS2.1	CS2.2	CS3.1	CS3.2
RS_1		✓		✓	✓	✓	✓	✓	✓
RS_2	✓		✓	✓	✓	✓	✓	✓	✓
RS_3	✓			✓	✓	✓		✓	✓
RS_4	✓		✓	✓	✓	✓	✓	✓	✓
RS_5	✓	✓	✓	✓	✓	✓	✓	✓	✓
RS_6	✓			✓					

4.2.1 AIRBUS's case studies technical specifications

4.2.1.1 Elementary tasks and tools

Based on the scenarios CS1.1 and CS1.2 described in Section 4.1.1, following a list of the various elementary tasks that must be combined and carried out at each step by the robot.

CS1.1 - Holes deburring of pre-drilled A320Neo pylon sub assembly

- Specification of the holes to be treated by the robot via an input file,
- Localization of the part by the robot camera,
- Computation of a path for the robot base to go in front of the part,
- Execution of the deburring motion for each hole via force and vision-based MPC (Model Predictive Controler).

CS1.2 - In orbit assembly process of large scale reflectors

- Estimate pose of already assembles parts,
- Grasp a new element with one arm,
- Position the element,
- Grasp a cleat
- Assemble the new element with the cleat.

4.2.1.2 Pilot constraints and associated technical risks

Due to the high cost of manufactured parts in the two use-cases, and due to the difficulty to access Airbus premisses for external people, the testing zone and the pilot zone will both be located at LAAS with dummy parts. For the deburring case study, the mockup is displayed in Figure 3 “Simplified setup for pylon deburring” (3D printed red mockup representing a pylon attachment). While for the in-orbit assembly process, we will use mockup parts assembled with cleats.

The technical risks identified are the following:

- TIAGo robot fails to achieve the required accuracy for inserting a tool in a hole,
- Localization software fails to localize the parts with the requested accuracy,
- Model predictive control algorithm fails to take into account complex meshes for collision avoidance with the required frequency.

If some of the above risks materialize, we will fall-back on more mature technologies like:

- using a fixed robot arm,
- using dedicated markers to localize the part,
- using position control algorithms.

4.2.1.3 Testing zone setup

Figure 9 Testing zone

The testing zone will be located in one of the robotic experimental rooms of LAAS. The mockup aircraft pylon will be placed on a table. The deburring tool will be directly mounted on a support compatible with the rapid tool change. The type and the fixation of the deburring tool to the robot end-effector to the robot is still to be defined. In the course of Task T5.2 PAL is working on the development of a tool changer to ensure the versatility of the AGIMUS TIAGo robots. The plan is that the integration of the deburring tool will also be done through Task 5.2. The initial plan is that the deburring tool will not be managed by the gripper, but it will be directly mounted on a support compatible with the tool changer that is under development.

4.2.2 KLEEMANN's case studies technical specifications

4.2.2.1 Elementary tasks and tools

Based on the scenarios CS2.1 and CS2.2 described in Section 4.1.2, following a list of various elementary tasks that must be combined and carried out at each step by the robot.

CS2.1 – False ceiling assembly

- Estimate the desired location of the reinforcement bars on the false ceiling
- Dispense glue on specific strips
- Spread the dispensed glue along a line (with a dedicated tool/end-effector)
- Grasp a metal reinforcement bar (with a dedicated tool/end-effector)
- Put down a frame support at a specific location on the first try
- Press with the tool on the metallic support to properly glue it (with a dedicated tool/end-effector)

CS2.2 - Floor assembly

- Dispense and spread glue evenly over a large hard surface (with dedicated tools/end-effectors)
- Dispense and spread glue evenly over a large semi-elastic surface (with dedicated tools/end-effectors)
- Take a dedicated tool to press the floor covering
- Press on the entire covering (with a dedicated tool/end-effector)

Furthermore:

- A common elementary task to be performed at most, if not all, steps of the two CS is for the robot to position itself in different locations around the workbench to carry out an elementary task (to reach the work area), possibly moving around the workbench during such elementary task as the work area may not be fully reachable from a single location. Such repositioning task may be performed while carrying additional workload (extra tool, support bar, ...).
- In the two case studies, the robot must also be able to get the precise 6D pose of various items that are not part of the YCB-V or T-LESS datasets, and some with variable dimensions based on the elevator being constructed.

4.2.2.2 Pilot constraints and associated technical risks

Current robotic deployments in industrial environments usually rely on highly-specialized, task-specific end-effectors (e.g., syringe or spray for glue dispensing, suction cups for grasping, ...) to achieve the desired precision, reliability and efficiency. Robotisation of industrial processes performed by human operators requires the development of dedicated tools, and most often a complete rethinking of the process itself.

Within AGIMUS striving for adaptability and also aiming at using versatile grippers (able to carry out various tasks) rather than highly dedicated solutions is mandatory. Also, AGIMUS's goal is to achieve the performance required for an industrial pilot.

Targets for CS2.1 and CS2.2 are:

- The use of off-the-shelves 2-fingers parallel fingers grippers for most tasks, with dedicated finger extensions for each elementary task when required,
- The use a of dedicated glue dispensers for each case study, as reproducing the operator's technique for glue dispensing/spreading with grippers is technically not feasible in an industrial setting.

While it is required, in the testing zone and the industrial pilot, some manual operations in order to change the fingertips or the end-effectors between steps, the future deployment of an automatic tool changer will allow for the continuous operation of the robot.

Following the on-site visit at Kleemann's site, several issues have been also identified that may hinder the transposition between the testing zone and the industrial pilot or constrain to industrial deployment:

- False ceiling panels may be manufactured with unpainted, highly reflective polished metal, thus acting like mirrors. In such settings, cameras and LIDAR will not be able to properly understand the scene. such materials for the case studies will not be considered
- Operators use their whole body when pressing, generating a lot of force that greatly exceeds what can be generated by the TIAGo AGIMUS robot's arm (the estimated operator's force is around 500N while the TIAGo robot's arm should be able to apply a force of around 50N. The actual ratio may be lower, as part of the operator's force is applied to overcome friction, but is still significant). This may have an impact on the overall quality of the finished product.

- On-site environmental conditions greatly impact the workflow. Indeed, in the floor scenario, waiting for the glue to dry varies between 15 minutes (in winter) and 5 minutes (in summer). This also impacts the maximum time to dispense/spread the glue (less than a minute), so that it is mostly at the same condition on the whole surface.
- When spreading the glue on the floor covering, the mat often slides on the workbench, requiring the operator to press on it to maintain it on the workbench. Furthermore, as the material is cut from a roll, two opposite sides significantly bend upward, which requires additional handling by the operator.

Based on these hard constraints, we restrict the CS and the steps in the following manner

- We only consider parts with non-reflective properties
- We do not consider the floor covering gluing step
- The experiments will be conducted in the environment (temperature, humidity) of the Testing Zone.

We also identified the following additional risks:

- Gripper limitations (precision, reproducibility, mechanical constraints)
- Extra tools (e.g., spreader, brush, rubber mallet ...) limitations
- Sensors' precision and latency

Proper evaluation of the integrated robotic platform must be carried out as part of T6.2 in order to identify its limits and the risks in the context of CS2.1 and CS2.2, and finalize the testing zone description.

4.2.2.3 Testing zone setup

The testing zone at Inria will replicate, in a limited space, the shopfloor's area of Kleemann.

- 2 square workbenchs each based on 2 trestles in the robotics lab to be able to put 2 floors, 2 ceilings or 1 ceiling/1 floor (to evaluate how the robot may chain experiments and deal with human operators nearby)
- 1 small workspace to store/prepare the support bars to glue in CS2.1 (ceiling)
- 1 small workspace to arrange the extra tools and work consumables

Liquids with the appropriate properties (viscosity, drying speed) will be used instead of the glues used in the industrial setting to avoid chemicals diffusion in the lab area (site safety regulation), as well as ease the cleanup and manipulation between experiments and allow the reuse of parts.

As mentioned previously, the case studies CS2.1 and CS2.2 will be deployed at Inria's Testing Zone on TIAGo SEA++ and in KLEEMANN's Industrial Pilot on TIAGo Pro. The difference, between these two versions of the TIAGo Agimus is related to how the arms are connected to the torso. This will change the workspace, especially when holding a part with 2 arms. Also, the specifications of the mobile bases may be different (path planning).

4.2.3 THIMM's case studies technical specifications

4.2.3.1 Elementary tasks and tools

Based on the scenarios CS3.1 and CS3.2 described in Section 4.1.3, a list of the various elementary tasks that must be combined and carried out at each step by the robot is following.

CS3.1 - Inserting small plastic pieces into the cardboard

- Localizing the cardboard sheet in the robot workspace
- Localizing the empty holes in the cardboard sheet
- Localizing the plastic piece
- Picking the plastic piece by the robot gripper equipped with a tool
- Inserting the plastic piece into the prefabricated hole

CS3.2 – Removing cardboard waste from the sheet

- Localizing the cardboard sheet in the robot workspace
- Pick-and-place cardboard sheet with an end-effector
- Localizing waste inside the cardboard sheet
- Removing the waste by the robot equipped with a tool

4.2.3.2 Pilot constraints and associated technical risks

Most of the existing robotic deployment in the THIMM shopfloor is based on the highly specialized robotical setup, where both hardware and software are tailored to the specific processes. High production rate, accuracy, and reliability are achieved by the specialized setup. However, robotization of small-batch industrial processes is not rentable with specialized approaches; therefore, agile production is foreseen. Within AGIMUS, one aim is to agile software that is deployable to novel scenarios easily. Although agility came at the cost of efficiency (w.r.t. specialized setup), we expect automatization with no time loss compared to human operators.

For the selected cardboard pilots (CS3.1 and CS3.2), we target the deployment of Kuka robots with dedicated end-effectors tailored to fine cardboard sheet manipulation and specific tools for plastic piece insertion and waste removal. The following constraints and risks have been identified from the on-site visit to the THIMM shopfloor:

- The cardboard sheets in THIMM production vary in size from a few centimeters to a few meters. Bigger cardboard sheets do not fit into the robot workspace; we will limit the case study to the smaller cardboard sheets based on the robot workspace.
- The cardboard sheets are flexible, which might cause difficulty in both perception and manipulation designed initially for rigid objects. The risk of reduced accuracy exists and needs to be analyzed for both case studies in T6.2.

- The accuracy of the perception might not be good enough for plastic piece insertion. The combined haptic and perception feedback will be used to mitigate this risk.

4.2.3.3 Testing zone setup

The testing zone at CIIRC, *i.e.,* CIIRC Testbed, will replicate, in a limited space, the relevant parts of the THIMM shopfloor. CIIRC Testbed for Industry 4.0 is a unique research and experimental workplace, the largest of its kind in Central and Eastern Europe. It serves for the development and testing of innovative solutions for advanced and fully integrated industrial production and processes for smart factories and is, therefore, prepared for the replication of relevant parts of THIMM small batch processes. To achieve that, THIMM will provide a representative sample of cardboard to develop and test both localization and manipulation skills for both case studies. The set of plastic pieces for CS3.1 will be supplied by THIMM as well. This will allow us to replicate the industrial pilot in the testing zone fully.

4.3 Risk identification and mitigation measures

During the WP6 bi-weekly meetings and the shopfloor visits as well, risk identification has been conducted, as it plays a key role in the success of managing risk.

While in the beginning of the project, organizational factors such as having an implementation strategy and ensuring case studies' implementation gained much attention, the importance of risk identification is already highlighted in the deliverable D1.1.

This section details the risks discovered either through site visits or in routine meetings that could potentially impede the progress of the case studies. For each industrial pilot, it is presented a distinct table outlining the technical risks, and a single consolidated table for all non-technical risks that are common across the pilots. After the risks are presented the proposed mitigation strategies to tackle these identified risks.

4.3.1 Case studies technical risks

Table 9 Airbus pilot's case studies technical risks and mitigation measures

No	Risks	Mitigation measures
1	TIAGo robot fails to achieve the required accuracy for inserting a tool in a hole.	We will use a fixed based robotic arm.
2	Localization software fails to localize the parts with the requested accuracy.	We will use dedicated markers to localize the part.
3	Model predictive control algorithm fails to take into account complex meshes for collision avoidance with the required frequency.	We will use position control algorithms.

Table 10 Kleemann pilot's case studies technical risks and mitigation measures

No	Risks	Mitigation measures
1	Impact of speed limits (safety regulations, effective workspace size) on glue spreading homogeneity	Add timing constraints when solving the path planning for the glue dispensing task. Validate first the spreading step on a small size elevator floor Control the environment to slow the drying process of the glue
2	Limited precision when extending the arms to reach the limit of the workspace	Validate first the spreading step on a small size elevator floor Favor moving around the workbench compared to extending the arms for precision tasks
3	Glue dispenser capacity (volume of glue)	Evaluate the required volume for single item and whole day production. Evaluate cost of dispensers depending on volume capacity. Devise procedures for monitoring levels, anticipating need, and informing the operator.
4	Glue dispenser cleaning complexity	Use disposable parts for testing zone. Devise automated cleaning procedure for industrial pilot
5	Inertia when manipulating long parts	Require handling of reinforcement bars with 2 arms
6	Pressure by robot not as strong as the one exerted by the operator	Evaluate the quality of the glued parts to identify the effective pressing force required.
7	Heavy friction of current pressing tools requiring too much force for the robot	Use rollers to apply downward pressing force without requiring extra efforts on the arm

Table 11 Thimm pilot's case studies technical risks and mitigation measures

No	Risks	Mitigation measures
1	Localization software fails to localize the parts with the requested accuracy.	Dedicated markers to localize the part will be used.
2	The perception is not accurate enough for plastic piece insertion.	The combined haptic and perception feedback will be used.

No	Risks	Mitigation measures
3	Manipulation of cardboard sheet is not safe for big flexible cardboards.	Manual transfer of the cardboard sheets will be used to move big sheets into the robot workspace.
4	The mechanical cardboard waste removal is not robust.	The compressed air will be used instead of mechanical removal.

4.3.2 Case studies non-technical risks

Apart from the technical risks specific to each industrial pilot deployment, additional non-technical risks have been identified

- Operators express significant concern that the introduction of multifunctional robots may lessen their importance.
- Operators require new knowledge and advanced skills to efficiently work alongside autonomous robots, to focus on more complex, value-added activities as well as to oversee the robot's operations.
- In industrial operations, safety and reliability are mandatory. One of the key pillars to achieve these goals is through effective inspection and maintenance practices.
- Seamless interoperability between robotic systems and existing equipment necessitates a common standard, which must undergo multiple iterations of change and optimization to fit all systems.
- Following the identification of a risk of mis-use of the technology developed in AGIMUS by a partner, there are significant risks that some components may not be open-sourced as anticipated. This may require careful evaluation of alternatives, additional planning to anticipate delays, and revised industrial exploitation plan after the project's timeframe.

The Table below summarize these risks and identifies mitigation measures to be implemented to alleviate them.

Table 12 Industrial pilot's case studies risks and mitigation measures

No	Risks	Mitigation measures
1	Employee resistance	Employees' participation in developing and implementing the new technology
2	Shopfloor disruption	Fully trained operators Workflow integration
3	Safe and effective operation	Regular inspection and maintenance programs Operators training and overhaul of safety procedures

No	Risks	Mitigation measures
4	Compatibility of existing devices with the new devices	Standardization efforts
5	Adaptability of robotic systems – Technical need	One robot with 3 components in total
6	Restrictions of the open-source availability of specific AGIMUS software components	Evaluate open-source alternatives for the relevant components Evaluate mid to long-term impact of alternative licensing policy

5. Conclusion

In this deliverable, we provided detailed descriptions of the case studies for the three industrial pilots, in particular identifying the specific steps that the TIAGo should achieve in order to demonstrate the versatility and effectiveness of the AGIMUS framework for agile production. Through on-site visits and direct conversations, the specific requirements and limitations of each case study were indicated, along with potential risks. These discussions, especially regarding the choice of end-effectors, played a crucial role in determining the optimal trade-off in each industrial pilot between employing universal grippers to illustrate adaptability and selecting specialized end-effectors for greater efficiency. The identified risks that may hinder the deployment of the AGIMUS' solutions, have been presented along with the mitigation actions that will reduce the impact. The output from this Deliverable directly contributed to the definition of the metrics survey template incorporated in Deliverable 6.4 on the evaluation and comparative assessment of the industrial pilots.

At this point, providing a detailed timeline and specific milestones for the implementation of the use cases is challenging. The primary reason is that there are still numerous unanswered questions and necessary experimentations surrounding the end-effectors for the robotic arms. End-effectors are critical for performing a variety of tasks. Determining the most suitable end-effectors involves considering factors such as versatility, efficiency, compatibility with different tasks, and integration with existing systems. As we explore these aspects through experiments and analysis, it will help us gain a clearer understanding of the requirements and potential challenges. This exploratory phase is essential for ensuring that the robotic arms are equipped with the best possible tools for their intended applications, which, in turn, will influence the overall project timeline and milestones. Once we have more concrete data and insights from these experiments, to be started once the models for the arms are available and preliminary work on a tool changer and a customizable gripper is completed, we will be in a better position to outline a more precise implementation schedule ahead of the T6.2 task.

References

Arents, J., & Greitans, M. (2022). Smart Industrial Robot Control Trends, Challenges and Opportunities within Manufacturing. Applied Sciences, 12(2), 937. https://doi.org/10.3390/app12020937