D6.3 - Construction of mechanical framework to mount robotics arms within a laboratory hood. Integration of setup using new components with the robotic arm. Includes acceptance testing of ROS middle-ware to ensure services provide full control of robotic arm along with integrated components.

Deliverable 6.3

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Deliverable Title	D6.3 Construction of mechanical framework to mount robotics arms within a laboratory hood. Integration of setup using new components with the robotic arm. Includes acceptance testing of ROS middle-ware to ensure services provide full control of robotic arm along with integrated components.
Deliverable Lead:	ASTECH PROJECTS LIMITED
Related Work Package:	WP6: Integration & Evaluation
Related Task(s):	T6.1 Hardware integration (AST, CEA, TUW, UOB) T6.2 Software Integration (AST, TECN, CEA, TUW, UOB) T6.3 Verification & Demonstration of Traceability Capability (AST, CEA, TECN, TUW, UOB) T6.4 Towards Certifiable Software & Hardware (TECN, AST, TUW)
Author(s):	William Speed Nirmal Raveendran
Dissemination Level:	Public
Due Submission Date:	30/12/2023
Actual Submission:	20/12/2023
Project Number	101017089
Instrument:	Research and innovation action
Start Date of Project:	01.01.2021
Duration:	51 months
Abstract	This deliverable report contains the details of the efforts made by Astech and other work package partners for the construction of mechanical framework to mount the robotics arms within a laboratory hood. And also, the integration of the setup using new components with the robotic arm. Includes the acceptance testing of ROS middleware to ensure services provide full control of the robot which are the main objectives for Milestone 3.

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Versioning and Contribution History

Version	Date	Modified by	Modification reason
v.01	05 Dec 2023	William Speed (AST) Nirmal Raveendran (AST)	First issue ready for first internal review.
v.02	12 Dec 2023	Patrick Mania (UOB) Carl-Helmut Coulton (INV)	Revision UOB#1 Revision Invite#1
v.03	13 Dec 2023	Anthony Remazeilles (TEC) Nirmal Raveendran (AST)	Revision & Corrections
V.04	19 Dec 2023	Nirmal Raveendran (AST)	Final version ready for submission

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1 Executive Summary

This deliverable describes the advancement of the TraceBot project in terms of the mechanical and electrical construction done for the single physical platform which was described has been detailed in the D6.2 deliverable. Hence this is an extension to the D6.1 and D6.2 deliverables respectively. The D6.3 deliverable also encapsulates the methods generated to verify and test the traceability and verification methodology integrated into the TraceBot system. The method or the test document produced to carry out the test scenarios is known as the “Failure Mode and Effects Analysis – (FMEA)”.

The integration efforts this year was mainly focused on the adaptation of the robotic arm of the TraceBot system for the proposed dexterous gripper developed by work package 2 leader CEA, along with the development of the test scenarios for the acceptance testing of the traceability and verification capabilities of the TraceBot system. The complete integration and testing of the gripper was achieved by the end of this year which was a key task for the completion of Milestone 3 of this project. The acceptance testing is scheduled to be carried out by the end of next Milestone.

The physical platform that has been showcased in the D6.2 deliverable and Milestone 2 has been refined with few new modifications, to enhance the performance of the entire system. A significant work has been conducted to gather each individual partners development into the unique demonstrator at Astech. Throughout the year there has been periodic bi-weekly and weekly meetings, in addition to presential integration workshops. These interactions were arranged to identify the potential issues raised by such integrations, to define the adjustments required, and to monitor the progress of the integration effort. This year the integration results were first highlighted during the Konstanz symposium, in the month of May 2023 using all the materials from Milestone2 at that period.

The efforts by all our partners this year have resulted in the quick adaptation of the TraceBot demonstrator system with the CEA dexterous gripper from the robotiq gripper and is now able to showcase the canister insertion into the pump tray, as well as the needle cap removal and the needle insertion into the bottle use-cases which are the two most matured processes that have been currently well integrated into the system located at Astech. Efforts where also put in updating the correct synchronization with the Digital Twin and the first version of the semantic audit trail is being obtained.

All these works are strongly related to the main objective of Milestone 3 of the project, which goes in a halfway point of the project cycle to demonstrate all the pre-proposed functionalities of the TraceBot system in a real environment. This document is providing light to some of the works achieved according to the Milestone objectives. We consider that most of the main objectives of the Milestone 3 has been achieved, even though some items still need to be implemented further into the future of the project timespan.

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2 Introduction

This document a detailed overview of all the integration outcomes achieved during the third year of integration of the TraceBot project and is in the continuity to the activities conducted during the first and second year, which was reported in the documents D6.1 and D6.2 respectively. Hence in Section 3 of this document we will discuss in detail of all the integration efforts and achievements that were made by the team. This section will shed light on the topics like “Hardware Integration”, “Software Integration” and will also give a detailed outline of the topic “Acceptance Test and Verification methodologies” used by the TraceBot system. Moving forward, Section 4 will have all the contributions made by all of our partners for this year. Finally, we will also be discussing the about the “Deviations” that has occurred in the work plan set for this year in Section 5.

After having showcased the use case demos towards the end of the year 2022 on the physical demonstrator as part of the Milestone 2, the third year of integration started off as a follow up of all those integration efforts. The main objective to start of this year was to follow up improving the process efficiency and repeatability of the use cases. This was very important because it was in this year that the acceptance test for the ROS middleware had to be tested for traceability and verification capabilities. Hence there was a very high concentration on perfecting the two initially developed use cases which are namely Canister Insertion into the pump tray and the Needle cap removal and insertion in the bottle.

On the mechanical and electrical construction part of this project this year, witnessed the addition of an electrical cabinet to enclose all the electrical power outlets and the controllers as showcased in the initial design during the D6.1 deliverable. There has been an addition of four more emergency switches around the table edge perimeter configured in a pair of 2 on each sides along with the actual E-stops on the robotic arm teach pendent. The initially proposed mechanical framework to enclose the TraceBot system was discarded as it was found to cause challenges to the effective functioning of the robot due to a system specification deviation in the proposed design and the physical system build. All these system builds where completed by the end of the month of June this year.

Also, this year the first Failure Mode and Effects Analysis – (FMEA) document was drafted by WP6 and this document consists of all the failure test scenarios and their potential causes and effects and the controls that needs to be implemented to tackle these challenges on the system. The initial draft was prepared and submitted for internal consortium review during the months of July and August this year. The final document after the review was developed by the end of September this year.

Then as we arrived at the end of this year the integration efforts where more concentrated towards the integration and adaptation of the TraceBot robot arms with the new CEA dexterous gripper from the existing robotiq gripper showcased during the D6.2 last year. This integration works where carried out physically by all the consortium members at the demonstrator facility setup at Astech during the month of November this year.

This achievement was obtained thanks to a significant integration effort by all of our work package partners which involved periodic integration follow-ups and several integration workshops.

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3 Description of work & main achievements

3.1 Hardware Integration

This section will explain in detail all the follow-ups that has been done on the hardware build on the TraceBot system with respect to the initial build of the demonstrator showcased in the D6.2 deliverable last year. Most of the system hardware architecture remains the same as that of the one detailed in the D6.2 deliverable (ref. Figure 1).

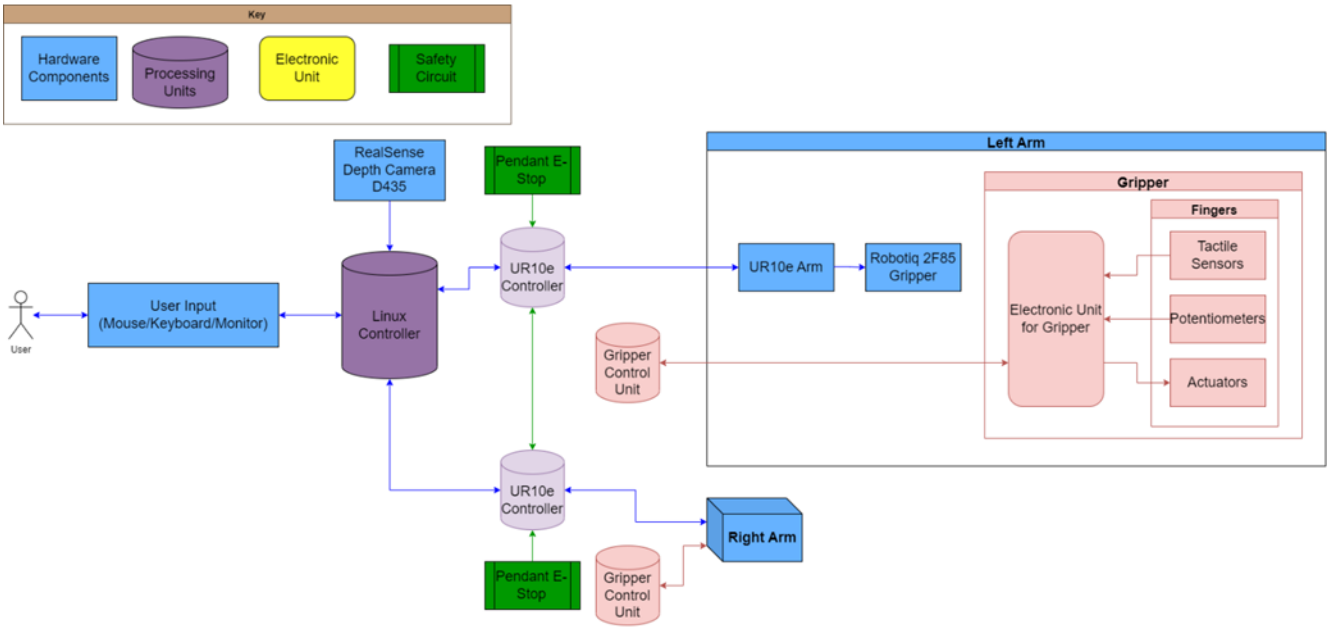

Figure 1: System Hardware Architecture

After having showcased the TraceBot system at the first demonstration last year for the Milestone 2, this year there has been few modifications made on both mechanical and electrical part of the initial build of the demonstrator to enhance the overall performance of the TraceBot system.

These modifications are mostly concentrated to enhance the performance and in particular we will highlight on the following aspects of the system.

1) Perception
2) Mobility
3) Safety

Perception :- As a result of carrying out repeated test runs of the use cases it was identified that the clear white surface of the tabletop which was showcased in the D6.2 (ref. Figure 2), has a disadvantage such that the surrounding light was being reflected back from the tabletop surface through the transparent objects such as the canisters and thereby making it difficult for the camera to accurately identify the canister object and estimate the pose of the object to perform the grasp action.

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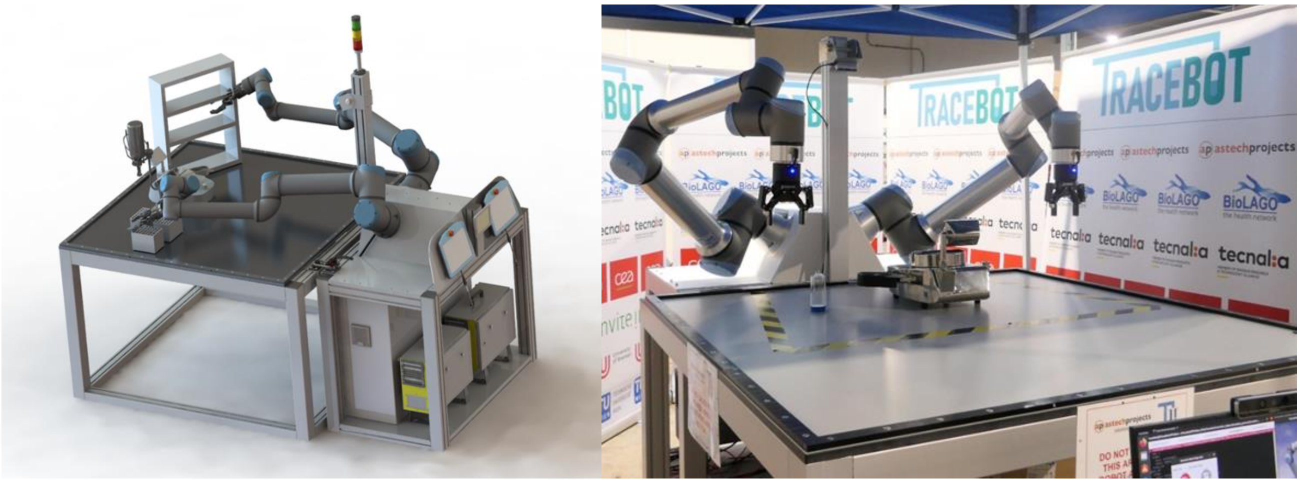

Figure 2: Final Proto-type Design and the Initial Build for D6.2

This challenge has been overcome by introducing a non-reflective black paper material onto the surface of the tabletop. This method helped us in reducing the light being reflected from the plain white tabletop surface and has helped us in enhancing the perception skills of the system. A gazebo was also introduced around the parameters of the TraceBot system as to control the surrounding environmental lightings. Later the setup was moved from its initial location to a dedicated space within a production lab setup with a better controlled environment lighting (ref. Figure 3).

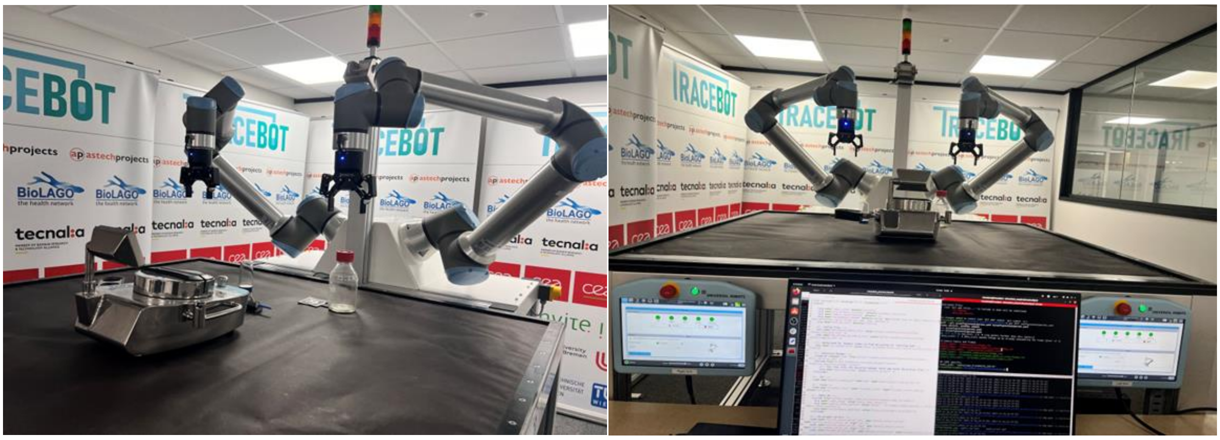

Figure 3: Modifications made to the initial build and setup installed in new location during D6.3

<u>Mobility</u>: - As the D6.3 deliverable mainly demanded the construction of a mechanical framework to enclose the TraceBot system within a sterile environment, this was a concept that was proposed during the D6.1 design planning report. But as the design concept progressed through reviews and suggestions from the consortium towards the final build which was showcased during the MS2 of the project mainly consists of two UR10e collaborative robotic arm rather than the earlier proposed UR5e collaborative robotic arm in the design planning phase during the D6.1 deliverable. The main reason for this change in the hardware component of the system is after taking into consideration the total payload weight of the proposed CEA dexterous gripper, which according to the WP2 team who are responsible for the development of the gripper is approximately 5.00kg in total with all the motors and the motor driver unit. Hence this weight constraint instigated the migration towards the use of

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UR10e collaborative robotic arm which is comparatively bigger and requires more space for operating safely and efficiently within the environment when compared to a UR5e robotic arm.

Due to this mechanical requirement of the arm, the proposed idea of building a mechanical framework structure to enclose the TraceBot system was discarded after discussing with the consortium members and the project leaders as it would oppose the smooth functioning of the system by supposedly acting as obstruction during the robotic arm joint manipulation process for joints such as the shoulders and the elbows. Hence, the final mechanical build of the TraceBot physical demonstrator doesn't include a mechanical enclosure framework. (ref. Figure 3)

Safety: - To enhance the safety of the operator and the surrounding environment there are measurements taken to install multiple E-Stops around the TraceBot Table perimeter. In the initial CAD design (ref. Figure 2) we can see that the only available E-Stop buttons where present only on the robot teach pendent and this was a challenge faced when needed to quickly stop the robot due to safety concerns. This challenge was overcome by installing a total of four additional E-Stop switches around the perimeter of the table for quick access to these in times of emergencies. The position of the teach pendent has also been modified from the proposed design, (ref. Figure 2) and has been mounted in the front of the system for easy access during testing (ref. Figure 3).

In terms of the electrical build after the D6.2 deliverable there were works carried out on the system to incorporate an electrical cabinet that encompasses all the electrical connections including the power switch and the ethernet switches as well as the robotic controllers. This was proposed during the D6.1 deliverable as well. The implementation of this can be seen in the below (ref. Figure 4).

With this the mechanical and electrical objectives put forward by the deliverable D6.3 has been met and was showcased before the consortium for approval during the months of May and June this year.

Figure 4: Electrical cabinet(behind) and the Robotic arm Controllers(infront)

The later months during this year of integration, saw the efforts being made on to integrate the physical demonstrator with the CEA dexterous gripper towards the end of the year.

The CEA dexterous gripper the adaptation of the TraceBot system from the existing robotiq 2f gripper to the new CEA dexterous gripper was fairly a straightforward implementation and installation thanks to the modular software architecture of the system with ROS middleware which gave the developers of the gripper a separate node for gripper server development and then that node being made to call by the ROS-Master and the controllers made the integration efforts much easier as faster. The entire

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process of installing the new gripper onto the TraceBot's UR10e arm was done within a timespan of one day after the gripper was available at the Astech facility. (ref. Figure 5)

This hardware and software integration was done during the physical integration workshop hosted by Astech. During this integration workshop the members from Tecnalia, CEA, TUW where present physically and the team members from the UOB partner was actively present remotely throughout the integration weeks.

Through this teamwork and efforts, we were able to achieve the objective of installing, testing, and recording the working of the CEA dexterous gripper with the two of the most mature use cases we have integrated within the system namely the Canister insertion into the Pump tray and the Needle cap removal and insertion into the bottle. The demonstrations of the working of the gripper with the TraceBot arm were showcased to the review board members during the 2nd review meeting held on the 29th of November 2023.

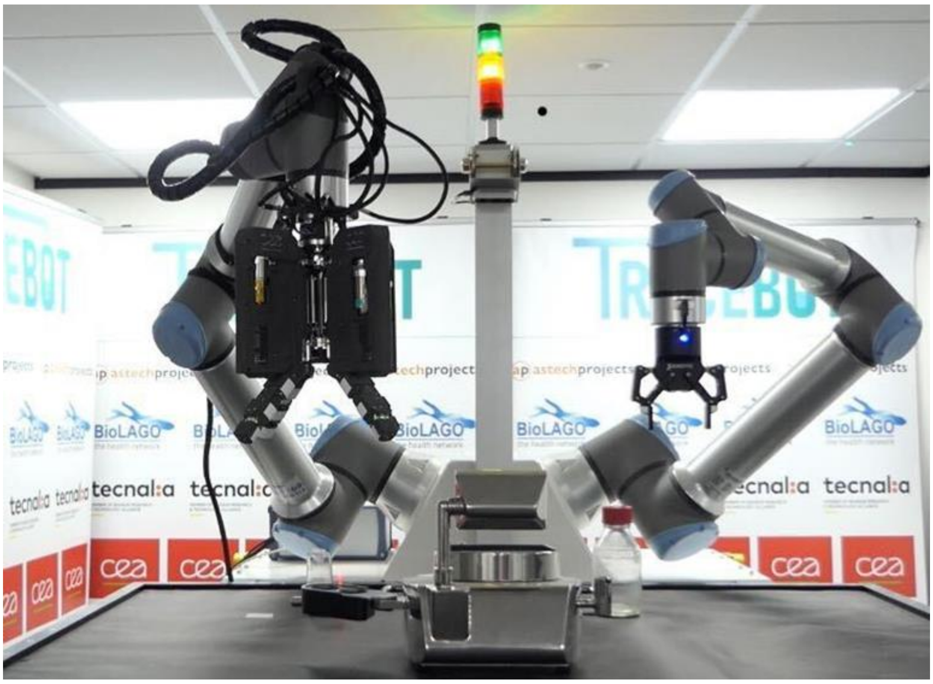

Figure 5 : CEA Dexterous Gripper Mounted onto the Right arm of TraceBot System as Astech

The CEA Dexterous gripper consists of three external hardware parts that needs to be mounted on to the TraceBot Arm during the installation process the parts being,

1) Gripper,
2) Motor driver unit
3) External controller unit

This modular structure of the gripper helped in the fast installation and adaptation to this gripper from the old robotiq 2f gripper (ref. Figure 6).

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Figure 6 : External Hardware Components of the CEA Gripper

<u>Gripper</u>: - The gripper is the most integral part of the TraceBot system as it is responsible for the grasping of objects that needs to be manipulated during the use cases processes of the TraceBot System. This dexterous gripper is a innovative custom machine with 18 DOF in total which has been specially designed for the TraceBot system alone such that it can bio mimic the human hand to a certain extent (ref. Figure 7).

Figure 7 : CEA Dexterous Gripper Fingers

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All the gripper specifications has been discussed in the WP2 documentations.[ref. Reference 1]

Motor Driver Unit: - This unit is responsible for driving all the motors that are embedded in the gripper fingers for producing the actuations of the fingers and also controls the motor on the 3rd wrist joint to produce the rotation motion of the gripper. This unit is attached to the UR10e arms of the TraceBot using a custom 3D printed brackets and holders (ref. Figure 6). More detailed electrical and mechanical architecture of the unit is discussed in IEEE publication documentation [ref. Refernece 2].

External Control Unit: - This unit acts as the extenal brains of the gripper as currently the control module is developed externally by CEA with respect to the Traebot system (ref. Figure 6). This controller is connected into the same local area network of the TraceBot using a RJ45 ethernet cable and an ethernet switch. The controller is commanded by the CEA server node that is embedded into the TraceBot software archietechure. The details of which can be found in the TraceBot official website [ref. Reference 1]

3.2 Software Integration

The software part of TraceBot also follows the same architecture as shown previously in the D6.2 deliverable where the core components are developed as ROS nodes and encapsulated into skillsets for ease of their usage through the Skill Execution Engine (ref. Figure 8).

The integration effort consists of (i) validating the development in the partner site, (ii) deploying the developments made by the partners on the physical demonstrator located at the Astech site, and (iii) making sure the combination with the other components is effectively functional.

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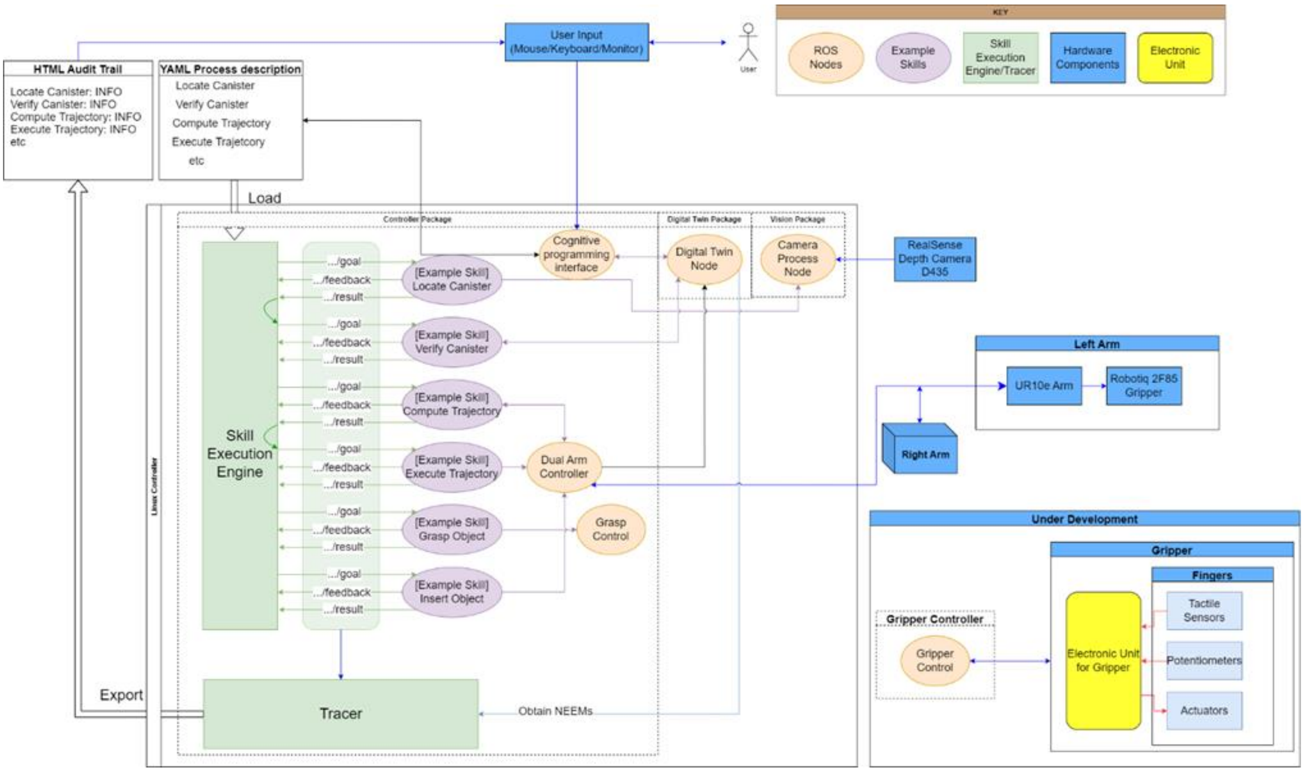

Figure 8 : Core Software Architechure

This year the software integration efforts were mainly concentrated on perfecting the perception node,the verification node and the integration of new CEA dexterous gripper to showcase the TraceBot system with the use cases. Significant efforts were also dedicated to update the Digital Twin (DT) with the new gripper model as well as with the managament of the new items, such as the bottle and the bottle holder. The main role of Astech as integrator was to deploy all these developments made by the partners onto the demonstrator and test it‘s functionalities throughout the development phase along with preparing the “Acceptance testing document for the ROS middleware“.

<u>Perception Integration</u>: - The perception layer uses the onboard Intel Realsense Camera to locate objects placed in the area of interest and currently using the “COPE“ method to estimate the pose of the objects such as the Canisters, Needle, Bottle, and the Pump for the two use cases (namely the Canister Insertion into the Pump Holes and the Needle Cap Removal and Insertion into the Bottle) and sending that information to the Digital Twin action server to verify the pose and spawn these objects into the Digital Twin virtual environment. After spawning the objects into the DT and verifying the poses the coordinates of these objects are passed on to the “Skill Execution Engine“ which inturn commands the arm’s of the TraceBot to move to the given position coordinates and this is called performing the grasp action and then the process is executed. This is the most basic working principle of the perception node.

As mentioned the section 3.1 after having faced issues with this node due to the uneven lighting conditions and the reflection of light from the tabletop surface we implemented a modification of covering out the white reflective tabletop surface with a non reflective black colour paper to reduce the amount of light reflected from the tabletop and we prepared a much better controlled lighting

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environment. Thanks to these adjustments, we were able to achieve a more accurate object detection and pose estimation results from this node.

This year also witnessed the first testing of the new “GDRNPP“ method for object detection and pose estimation which would mainly be used for locating and estimating the pose of the of the needle item. This additional method is proposed since the “COPE“ is designed for handling transparent objects such as the canisters or bottles. The “GDRNPP“ method is currently being further tested (ref. Figure 9), before it’s full integration within the TraceBot demonstrator in the next year. The more detail of this method and the node can be refered to with the WP4 documentations [ref. Reference 1].

Figure 9 : Needle located using Gdrnpp method in rviz

<u>Verification Integration</u>:- This verification layer is a key component for providing the required traceability through the audit trail. The initial audit trail was provided through the logged information by the Tracer developed in Work Package 4, as illustrated in Figure 10.

With the progresses in Work Package 5 and the KnowRob system, a new version of the audit trail could be prepared. This new version relies on the semantic reasoning of the KnowRob system to drive the verification process, and gathered traces that contains more semantic information and non verbal explanation of the operations that took place.

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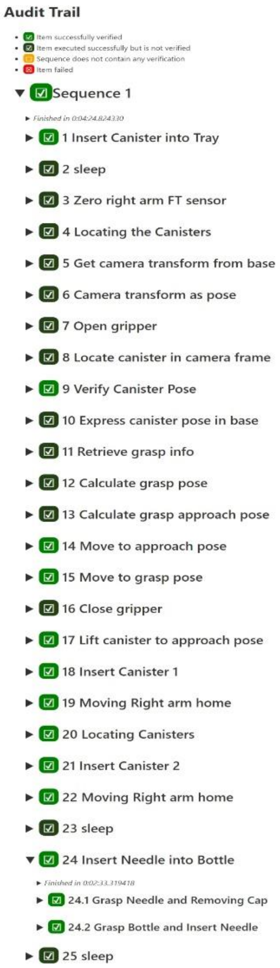

Figure 10 : Initial Sequential Audit Trail

Figure 11 illustrates the new version of the audit trail, incorporating semantic description of the conducted operations. The output is a pdf file that is also enhanced with images captured by the camera sensor during the process execution. As a first integration test of this functionality was obtained at the end of the year. Latest development of the KnowRob was integrated, and the TraceBot processes (skill sequence describing the operations to perform) were significantly adjusted to link the skills with their respective correspondences within the TraceBot ontology. In that first integration and validation, the verification was limited to the detection of objects within the gripper. We expect in the next period to incorporate more verifiers, related to visual and tactile cues, as well as through the Digital Twin, as developed in Work Package 4.

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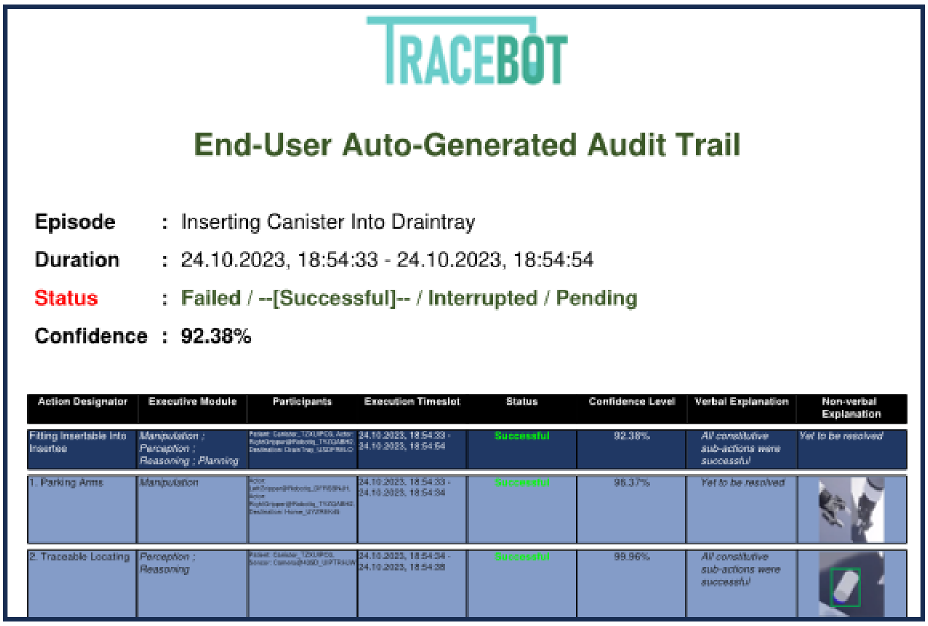

TRACEBOT

End-User Auto-Generated Audit Trail

Episode : Inserting Canister Into Draintray
Duration : 24.10.2023, 18:54:33 - 24.10.2023, 18:54:54
Status : Failed / --[Successful]-- / Interrupted / Pending
Confidence : 92.38%

Action Designator	Executive Module	Participants	Execution Timeslot	Status	Confidence Level	Verbal Explanation	Non-verbal Explanation
Fitting Insertable Into Insertee	Manipulation ; Perception ; Reasoning ; Planning	[illegible]	24.10.2023, 18:54:33 - 24.10.2023, 18:54:54	Successful	92.38%	All constitutive sub-actions were successful	Yet to be resolved
1. Parking Arms	Manipulation	[illegible]	24.10.2023, 18:54:33 - 24.10.2023, 18:54:34	Successful	98.37%	Yet to be resolved	
2. Traceable Locating	Perception ; Reasoning	[illegible]	24.10.2023, 18:54:34 - 24.10.2023, 18:54:38	Successful	99.96%	All constitutive sub-actions were successful	

Figure 11 : Non Verbal Audit Trail Illustration

Digital Twin Integration: - With respect to the digital twin interface node of the TraceBot system the focus was to integrate the URDF model of the new CEA gripper into the Digital Twin virtual environment. There has also been works carried out this year to incorporate the DT with the URDF models of the needle and the bottle which are used for the needle insertion use case (ref. Figure 12). There has been extensive works carried out in the DT to encapsulates the verifiers required by the knowrob Knowledge base to generate the audit trail.Currently the system has all the basic visual functional verifiers inplace to generate a basic version of the audit trail and this will be further extented with the inclusion of the tactile feedback functional verifiers to provide a more comprehensive non verbal semantic audit trail in the coming months to showcase the traceability functionalities of the TraceBot system.

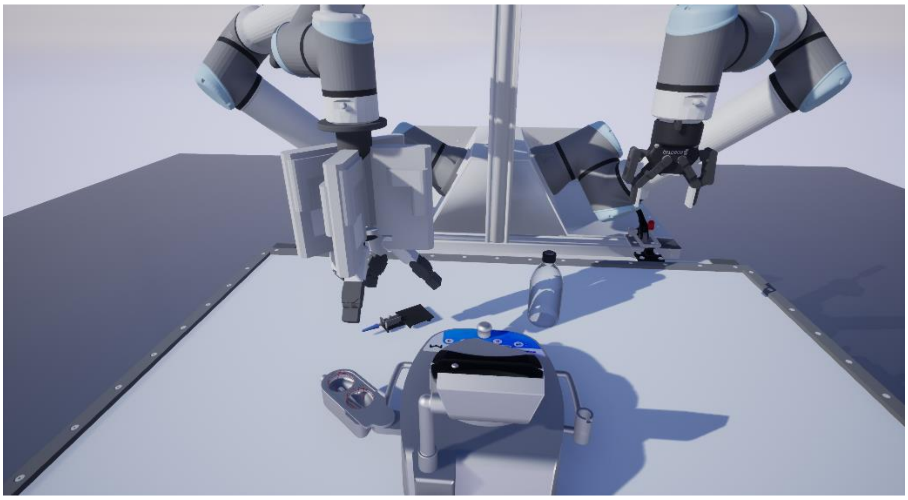

Figure 12 : Digital Twin with the new CEA gripper integrated

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Use Case Demonstrator States: - With Milestone 2, a first integration of the canister and the needle manipulation was available, in the standalone version. For the first TraceBot symposium as Konstanz in May 2023, we prepared a showcase version in which the two use-cases were sequenctially executed as part of a single process.

The demo video of the entire process was recorded by a professional videographer and the final output of the process along with the final audit trail generated (ref. Video 1) was showcased.

As previously mentioned, the processes associated to these two processes were deeply updated to be aligned with the new requirements of the tracing and verification modalities, while maintaining the same manipulation capabilities.

The other uses cases associated with the third Milestone (bottle placement in the bottle holder, red cap insertion on the canister and clamp manipulation) were implemented as TraceBot processes and demonstrated at Tecnalia, but not yet deployed to Astech. These manipulations were also executed at CEA with the dexterous gripper using atomic demonstrator, to showcase the capability of the new gripper for performing these operations.

Through the preparation of the following Milestone 4, we will consider their deployment at Astech, considering that the main objective of the following integration is to demonstrate an extended combination of standalone use cases into a single manipulation flow.

Finally the works on the demonstrator towards the end of this year was mainly dedicated with the adaptation of the use cases, the TraceBot processes with the use of one CEA dexterous gripper instead of the Robotiq gripper. As previously mentioned, the hardware and software integration upgrade was facilitated thanks to the previous integration coordination. The videos generated as Astech(ref. Video 2 and Video 3) showcase this progess made in the integration.

3.3 Acceptance Testing and Verification Methodology

In addition to the hardware, mechanical and software integration previously mentioned, the validation of the obtained demonstrator is also a duty assigned to Work Package 6. The objective is to verify that the integrated system is providing the expected outcomes, in term of manipulation, verification and generation of the audit trail.

This activity can be related to the generation of a Failure Mode and Effects Analysis (FMEA), which is a common step in the testing and validation of many devices, in particular in the pharmaceutical domain where Good Manufacturing Practices are to be followed. Astech, as one of the leading partners for the laboratory and pharmaceutical automation, is used to such practice, as it is a standard stage in the development of the robotic devices developed in this domain.

The Good Manufacturing Practices (GMP) is critically important at Astech, in order to ensure consistent quality and safety of products across manufacturing, industrial and pharmaceutical industries. These are 5 key P's of GMP that we follow, and they are: -

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1) **Products: -** Thorough testing and quality assurance are crucial steps in the product lifecycle to ensure they meet the desired standards before being released to clients. All materials and components have clearly defined specifications, and all meet strict quality standard.
2) **Processes: -** Clear, consistent, and well-documented processes are essential to effective GMP. These documented processes are made accessible to all employees, and regular evaluations are conducted to ensure compliance and alignment with the Astech's quality standards.
3) **Procedures: -** Procedures play a pivotal role in achieving consistent results. All employees are familiar with these procedures and follow them diligently. This adherence to procedures ensures consistently high-quality output and quality conformance.
4) **Premises: -** The condition, organisation and maintenance of premises directly influence product quality. Equipment placement, proper storage, and regular calibration are crucial to ensure their optimal functionality and reliability, thereby producing consistent results and preventing equipment failure risks.
5) **People:** - Astech's personnels form the foundation of a successful GMP implementation. All employees strictly follow quality processes and regulations. To ensure this, regular training and full-process reviews are carried out.

Following this standard practice, Astech generated an extensive analysis of the possible failure modes that could affect the TraceBot system.

The FMEA is a set of tests that are carried out under the supervision of a Quality manager, Health and Safety manager, Project manager and the required developer and technicians. This document provides the level of assurance of the robustness of the machine built when executing a repeated process for a prolonged time during its commission life.

The FMEA is carried out by setting the system in a predefined configuration and then the developer along with the Quality Manager and Health & Safety manager test the accuracy and response of the system to the challenges that are thrown towards the system.

Proposed FMEA methodology: - Currently it has been decided to carry out a FMEA test to check if the TraceBot will respond accordingly.

Nevertheless, the execution of the complete FMEA would be very time consuming, and would require to dedicate significant time in aspects that are not directly related to the core development of TraceBot, but more related to the generation of a robust prototype for deployment. We therefore decided to focus on the failure modes that are directly related to core development of the TraceBot project (like the perception, arm motion control, object manipulation, process verification and process tracing).

To do so, we breakdown the entire FMEA tests into parts that corresponds either to specific TraceBot processes (like the canister and needle manipulation) or to the aspect that will be omitted in our validation actions. These two categories are respectively highlighted in green and red colour in the snapshot of the FMEA in the figure below (ref. Figure 13). Our objective is then to challenge the system by making the failure to happen (like for example by moving intentionally the object after its automatic detection and pose estimation, and before the robot tries to grasp it), to make sure the system is able to detect the failure situation, and at least to detect and report it within the audit trail system.

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Even though the execution of these acceptance tests were supposed to be conducted already, we decided to postpone it until the verifiers developed in Work Package 5 gets integrated within the TraceBot system and inserted into our demonstrator, even though the current KnowRob system is ready to drive the verification process according to the current action taking place. This will also enable us to validate the verifiers related to the gripper system, as many verifications are related to the data collected by the gripper and its embedded tactile sensors (with the CEA dexterous gripper).

The initial daft of the FMEA document was prepared at Astech by the month of July 2023 and shared within the consortium for internal review in September 2023 and the final FMEA tests on the demonstrator are scheduled to be carried out as early as March 2024 when all the functional verifiers are in place in within the ROS-middle-ware program.

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Potential Failure Modes and Effects Analysis (Design)

Company	ASTECH PROJECTS	**Issue Level**	1
Equipment Name	TraceBot	**Issue Date**	
Part No./ id		**No. of Pages**	
Assembly Function	Traceable Robotic Handling of Sterile Medical Products		

Risk Priority Number (R.P.N.) Summary

RPN	RISK	RECOMMENDED ACTION	INITIAL COUNT date	REVISED COUNT date	REVISED COUNT date
1-100	Low	Action not required	55		
100-250	Medium	Some action required	0		
250+	High	Action mandatory	0		

Title:	TraceBot		Colour Legend	RPN: >/= 343
Equipment Category (PL) :	D	Initial FMEA Date:		RPN: 100 to 342
Document No.:				RPN: 1 to 99

No.	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) of Failure	Occurance	Current Controls	ALARP	Potential Test Scenarios	R.P.N.	Recommended Actions	Responsible
		system failure			/ electrical circuits breaks							
7a	7. Device Transfer	Failure to pick up canisters	Right arm fails to insert canisters.Sequence moves forward to the next process.		Canisters missing, canisters in wrong orientations, vision system failed to detect the canisters.		Lighting is controled for the ease of detection of transperent objects, verification of closed gripper pose		a) Unachievable position b) Obstacle in the path c) Objects fails while the arm move	0		N/A
7b		Failure to release Canisters			Obstruction detection by arm, Position misplaced leading to arm triggering the safety limit E-Stops.		Verification of the open gripper pose.			0		N/A
7c		Failure to pickup Needle	Right arm fails to grap the		Needle missing, Needles in wrong orientations, vision system failed to detect the Needle.		Verification of the close gripper pose.Verification from the fiducial object.			0		N/A

Figure 13 : FMEA Test Demo Sheet

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4 Link to Milestone 3

The deployment of the developments into the Astech demonstrator is clearly part of the Milestone 3, but this Milestone also refers to other items that are now briefly detailed, according to the means of verifications that were defined in the Description of Action.

[WP2] Multifingered gripper used for unimanual manipulation.

The gripper developed was tested at CEA and it was demonstrated that it can indeed manipulate all the items involved in the use cases considered so far. Similar demonstrations could be also obtained at Astech, with the gripper mounted onto the demonstrator. This gripper was also there incorporated into the more stable and complete use cases that are the canister and the needle manipulation processes, as illustrated with the demonstration videos.

[WP2] Tactile sensing functionalities used in robot controllers.

The tactile sensors are now embedded into the multi-fingered gripper. Experimentation at CEA could demonstrate the capability of sensing the interaction with the objects while grasping them. The tactile sensing could not be fully integrated within the TraceBot processes, it is envisioned to be done within the first semester of 2024.

[WP3] Bimanual operation

The needle manipulation, already demonstrated in Milestone 2, is involving the two robotic arms. The management of the red cap insertion onto the canister is also performed using both robotic arms. This demonstrates the capability of our architecture to handle jointly the two arms. These processes do not require a simultaneous control of the two arms. We envision to demonstrate this functionality with the tube placing onto the pump machine, which is scheduled for the next Milestone.

[WP3] Learning demonstration embedded in GUI framework.

We demonstrated (in the technical report and in the project review) various modalities for using learning by demonstration:

- to teach an adjustable trajectory, through Dynamic Movement Primitives, which would correspond to a single skill demonstration,
- to directly teach a set of skills, thanks to the analysis of the spatial relationship in between the objects of the scene and the robot gripper in the environment
- to teach a process and recognize in it the skills that are already known by the system, relying on the semantic information associated to each of these skills.

In the three modalities, we demonstrated the capability to teach to the robot the behaviour to learn, and to get the robot reproducing them. The two last modalities are accessible from graphical interfaces, which provide to the programmer convenient modalities to use them.

[WP3] Demonstration of programming a sequence of skills in the unified cognitive programming framework.

The graphical interface developed in WP3 is providing two means of programming. The first one is related to the manual selection of the successive skills to be executed. The second method is related

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to the previous point and uses a manual kinaesthetic teaching to show the required manipulation, letting the system recognize the skills that are involved in the demonstrated session.

[WP4] Traceability framework verified on use case.

The traceability functionality was already demonstrated in Milestone 2. Even though we reduced its contribution to the generation of the audit trail, it is still active and collect traces of the successive skills executed by the robotic system.

[WP5] Final definition of the TST software.

The latest deliverables of WP5 provided the final structure of the Treaceable Semantic Twin. It has been validated at UOB, and we are now deploying it onto the demonstrator, adapting the implemented processes to make full usage of it.

The definition has been driven by the constant integration of the TST with the demonstrators in the TraceBot project, clearly highlighting the necessary features to connect a game engine based Digital Twin with real world robotic systems. By incorporating the kinematic structure and manipulation operations into the TST, we had the opportunity to validate our acquired simulation and reasoning requirements and adapt them to provide a suitable platform for further experimentation.

[WP5] TST used for detecting failures in handling process.

As desrcibed in WP5, the verification processe is now leaded by the TST, which triggers the appropriate verifiers depending on the purpose of the current skill according to its description within the ontology. The system is prepared to incorporate multiple modalities into a coherent framework for verification. We could demonstrate its usage for detecting the failure of grasping an item (due to an intended manual displacement of the targeted object just before its automated capture). With this proof off concept, we will progresssively complete the integration of the other verifiers developed in WP4 within this framework.

[WP6] Intermediate hardware setup using first version of framework to allow use within a laboratory hood.

This document has described the progresses made on the physical demonstrator located at Astech, demonstrating the integration of various developments of the project. This demonstrator is a good showcase of the TraceBot development to raise awareness to the scientific and industrial community.

[WP6] Verification testing of Integration.

In the present document, we have described the proposed methodology to conduct the verification of the integrated system through acceptance tests, in the spirit of the work conducted traditionally using Failure Mode and Effect Analysis. The failures associated to our development are identified and related acceptance tests have been defined. We decided to postpone their execution to be able to conduct them with the latest verification framework which is now available. We are thus now able to validate the different verifiers as soon as they are integrated within the demonstration system.

[WP7] Key end user discussion groups created and met.

Several stakeholders are members of our Advisory Board, and we now maintain a bi-annual follow up and exchange with this group. Our first symposium enabled to increase our dissemination and to get more feedback on our work. Specific actions are also conducted with the regulator bodies through Work Package 7, and this activity is planed to continue in the following year.

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5 Deviations from the workplan

There have been no major deviations in work plans according to the integration efforts of the use cases when considered throughout the year. The only major setbacks in the entire work plan for this year was faced during the build of the electrical cabinet on the TraceBot demonstrator at Astech. This delay in timeframe was caused due to the unexpected supply chain difficulties due to strikes in the logistics side of the components supplier companies which subsequently delayed the maintenance works on the TraceBot system.

Another major deviation from the proposed work plan was to complete the acceptance testing by the end of this year. We decided to focus our effort in 2023 on the integration of the different development, both software and hardware, waiting to get a more stable verification layer and first integrated verifiers, compatible with the verification requirements provided through the KnowRob system. A first validation of the framework was conducted in 2023 to obtain the new audit trail, and we demonstrated the capability to connect to a verifier and to detect grasping failure. The system is thus now ready to receive more verifiers, and we plan to progressively test them as we integrate them into our demonstrator.

The only functional verifier currently implemented is the visual verifier and this alone cannot provide the sufficient level of compliance needed to carry out an acceptance test at this point of time. This is because right now the system processes are designed and integrated in such a way that the process would carry on running even if the objects are removed from the visual perimeter of the camera since the system only scans for the objects at the start of the process and then continues to execute the process even if the object is not present at that position during the grasp process. This behaviour of the system is due to the lack of tactile functional verifiers of the system. Thus, the only way to check for the visual verifiers is to remove the object before the start of the process such that the camera cannot locate the objects initially itself and this will send out an error message stating that the process cannot be executed as there is no object located to grasp during the process. This is the current state of the integrated visual verifier of the TraceBot system.

Hence due to this reason a full-on acceptance test cannot be carried out at such a premature state of the system and can only be carried out once the tactile functional verifiers are also integrated into the TraceBot demonstrator at Astech. This new verification framework will enable us to carry out a full-fledged acceptance testing process on the demonstrator.

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6 Conclusion

This deliverable presents information on the advancement of the integration process after the completion of the third milestone. The main outcome of this deliverable is the integration and deployment of the CEA dexterous Gripper at the demonstrator site at Astech, and it's usage for the manipulation of the canister and the needle with a bi-manual system, involving the perception layers for detecting these objects, as well as the bridge with the Digital Twin to maintain an updated robot belief state of the overall scene.

The document highlighted the work conducted to reach the final stage of integration of the physical setup, with all the main physical items integrated on the demonstrator. On the software side, the main integration aspects have been also inserted.

The use case canister insertion in the pump tray and the needle cap removal and bottle insertion are the two of most mature use cases for execution on the demonstrator, as it is fully integrated into the main software with all the items previously mentioned. Additional works are needed on the Red Cap management use case and the Clamp manipulation use case, as the deployed system is as of today is still pending to be tested with these use cases. The needle detection with the "GDRNPP" method of perception layer is functional at the demonstrator site, but some adjustments of the integrated process are still needed to finalize this part. This should be achieved in the following weeks to come or as early as beginning of next year.

The achievement of this integration has been facilitated by the establishment of a periodic integration meeting during 2023, initially bi-weekly, and then after summer 2023 on a weekly basis. During these meetings, all partners provided an update of their individual developments, while considering the additional adjustments required to combine the different contribution into the unique demonstrator site. Additionally, two physical integration workshops were performed, one at BioLAGO, Konstanz, Germany, in May 2023, and another one at the demonstrator site at Astech in November 2023. In addition to these physical integration meetings, there were also remote integration workshops conducted by integration partners to perform real time integration on the demonstrator on a software level. These integration workshop sessions helped a lot to speed up the integration efforts throughout the year. In total there were three remote integration workshops sessions conducted this year mainly during the months of June, August, and October 2023 respectively.

In 2024, we envision maintaining the periodic integration meetings, to continue improving the generated demonstrator, to prepare the integration of the additional developments of the partners, including the integration of the dexterous gripper on both the demonstrator arm along with the integration of the tactile sensing capabilities of the gripper, and to manage the next use cases envisioned for the fourth milestone. It is also planned to carry out the full acceptance testing and verification methodologies for quality and robustness testing next year as well.

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7 Annexes

7.1 Table of Videos

The of demonstration videos is made available on the TraceBot YouTube Playlist to showcase the advancements of the integration and development made.

- Video 1- 2023 05: - The Single TraceBot Use Case Demo "Canister Insertion into Pump Tray and Needle Cap Removal and Insertion into Bottle"

- Video 2 – 2023 11: - The TraceBot Use Case Demo "Canister Insertion into Pump Tray"

- Video 3 – 2023 11: - The TraceBot Use Case Demo "Needle Cap Removal and Integration into Bottle"

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8 References

1. https://www.tracebot.eu/deliverables.html

2. J. M. Escorcia-Hernández, M. Grossard and F. Gosselin, "A Methodology for early design specifications of robotic grippers," 2023 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM), Seattle, WA, USA, 2023, pp. 616-622, doi: 10.1109/AIM46323.2023.10196258.

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