



## WP8 – Use-cases set-up and on-site validation

### D8.1: MERGING robotic system validation on SELMARK use-case

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#### Summary

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This demonstration will show the robotized workcell prototype at SELMARK premises, and its evaluation in near-real industrial conditions. This use-case addresses the handling of bra cups fabric pieces during the thermoforming process, an intermediate production stage in the whole process of manufacturing a final lingerie or bath product.

## Executive summary

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This report documents the integration activities at SELMARK premises for the deployment of a robotized workcell prototype for the automatic handling of fabrics during the thermoforming process of bra cups. The report outlines the core technological modules of the Merging solution, and it continues with a description of its operation. The controlled real scenario, regarding the thermoforming process, demonstrates the system handling strategies and capabilities. This report consists of a supplementary description of the SELMARK demonstration video (internet link for its download is provided in the first paragraph of this document) towards the complete comprehension of the implemented functionalities and integrated results.

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## 1. Introduction

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This report describes the submitted demonstration video deliverable that concludes the activities of task T8.1. The document highlights key aspects and functionalities of the demonstrated manufacturing process as well as outlines the core technological modules that contributed to the integrated result. The report consists of the following sections:

- Section 2: summary of integration activities at SELMARK
- Section 3: all hardware devices composing the cell and its required calibrations to integrate software
- Section 4: software module required and configurations
- Section 5: process sequences and tests of the different modules
- Section 6: concluding remarks and outlook

The video file that showcases the demonstrator's operation described here, can be found at this link hosted by LMS servers:

- <https://syrios.mech.upatras.gr/nextcloud/index.php/s/SfkELZTq7Gep9xf>
- *using password : H2020\_MERGING\_WP8*

## 2. Integration activities

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The demonstrated result is the combination and integration of the different technologies developed in the work packages WP3, WP4, WP5 and WP6, as well as integration activities in the context of WP7. In WP8, to install and configure all the technologies, different hybrid and physical workshops at SELMARK were needed. Figure 1, Figure 2 and Figure 3 show the partners at the physical workshops.



*Figure 1. AIMEN's integration activities at SELMARK.*



Figure 2: CEA's integration activities at Selmark



Figure 3: Omnigrasp's integration activities at Selmark

The integration activities of the different technologies were carried out at SELMARK's premises. We can divide this work in three integration phases. In the first one, AIMEN implemented the robotic cell, the communication with the press, the installation of cameras for the SSM, the installation of the computer infrastructure, servers, and communications between the different elements, and most of the use-case tests were carried out. Afterwards, CEA carried out the integration of the virtual reality programming system (SPIRE). Then, OMNIGRASP came to do the final grip testing with the new EA gripper developed. Finally, CEA came again to finalize with the virtual reality system to program robot trajectories.

### 3. Hardware integration

#### 3.1. Work-cell integration

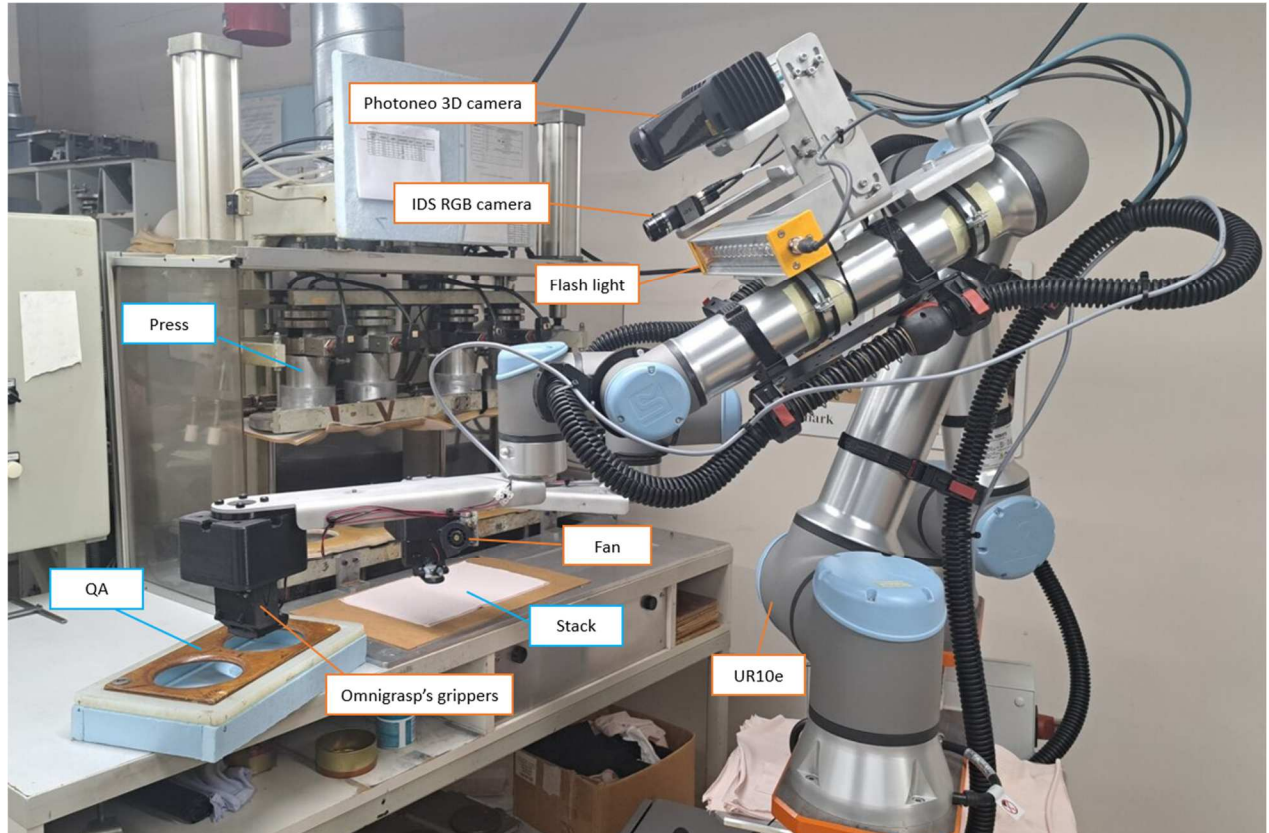


Figure 4. SELMARK robot cell.

#### **Robot cell transport to SELMARK**

To integrate all the equipment in SELMARK facilities, Photoneo was removed from the robot, to transport the system composed by robots and press. Therefore, the electrical installation was not modified with respect to the presented work in deliverable 7.1 “Report on integration”, section 3.3.1. and deliverable 7.2 “Workcell integration – Final version including interfacing”, section 3.1.

#### **Robot cell positioning**

Furthermore, we rotated the robot base 15 deg to the press, magnitude similar to the value we had at AIMEN facilities (14.47 deg). With this value, we modified the digital model of the cell in Rviz (Figure 5).

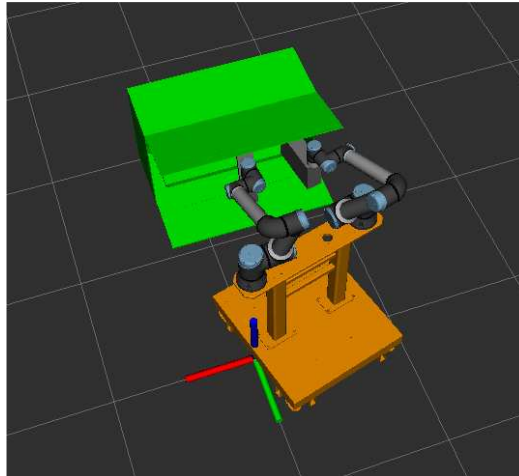


Figure 5. SELMARK digital model.

### **Electrical robot base cabinet**

To control the press through ROS framework, this must be in automatic mode. A signal was connected from the press to the robot to enable it with a digital output. This signal must be on for 5 seconds to ensure its correct performance. Then, a digital input will enable to inform that the thermoforming of the fabric was completed. See deliverable 7.2 “Workcell integration – Final version including interfacing”, section 3.1.2 for more information.

### **SICK laser scanner**

See deliverable 7.2 “Workcell integration – Final version including interfacing”, section 3.1.1 for information.

### **Automatic quick tool changer**

Finally, this technology was not needed in the final solution. This tool changer was intended to be placed in robot TCP in case not a huge accuracy was obtained for the Photoneo calibration, due to the fact that we mounted it at Joint 3, reducing the DOF to induce movement to the camera. Nevertheless, we have seen that calibration was quite accurate to avoid changing the tool during production sequence.

See deliverable 7.2 “Workcell integration – Final version including interfacing”, section 3.1.4 for information.

## **3.2. IT integration**

The initial idea was to run everything on the Dell server. During the implementation of the use-case, incompatibilities arose that made it necessary to add new devices to the deployment (Figure 6).



Figure 6: IT devices at Selmark

### **Ethernet switch with PoE**

Equipped with 48 ethernet ports (24 of them PoE) and 2 ports for fiber optics. All hardware devices of this use-case are connected here.

### **Jetson Orin**

With Ubuntu 20, ROS Noetic and CUDA. The People Detection and Tracking & Movement Decomposition and Speed Separation Modules are executed here. See section 4.3 of this document for more details.

### **Barebone PC**

With Ubuntu 20 and ROS Noetic. The Omnigrasp's grippers are connected, and their drivers are executed in this computer. See section 4.6 of this document for more details.

### **Desktop PC**

With Windows 10, VM Linux and ROS Noetic. CEA's hardware and software are connected and executed here. See section 4.7 of this document for more details.

### **Dell server**

With Ubuntu 18 and ROS Melodic. The rest of software modules are executed in this server.

## 3.3. Device integration

### **Stereo camera calibration**

Stereo cameras were installed around the cell (Figure 7). They were installed in different places and the best position for the detection of people was studied. After that, it was necessary to calibrate the system with a chess pattern. This is done to correct for lens distortion and to know the position of one camera relative to the other. Finally, the different modules that use those cameras were tested to check that everything works.



Figure 7: Stereo camera system at Selmark

### Camera-World calibration

To be able to transfer cameras information to the robot system, camera to world calibration was performed. Hence, we took 12 pictures of the robots to point its TCP to match this point to the one obtained from the image. In Figure 8 two of these images are presented with interest points highlighted in red.



Figure 8. Example of Camera-World calibration input images.

### EA Grippers

Before the technical team from OMNIGRASP came to SELMARK facilities, a first approach was done with electromagnets (Figure 9). In this case, these magnets were directly connected to robot signals to control its activation or deactivation.

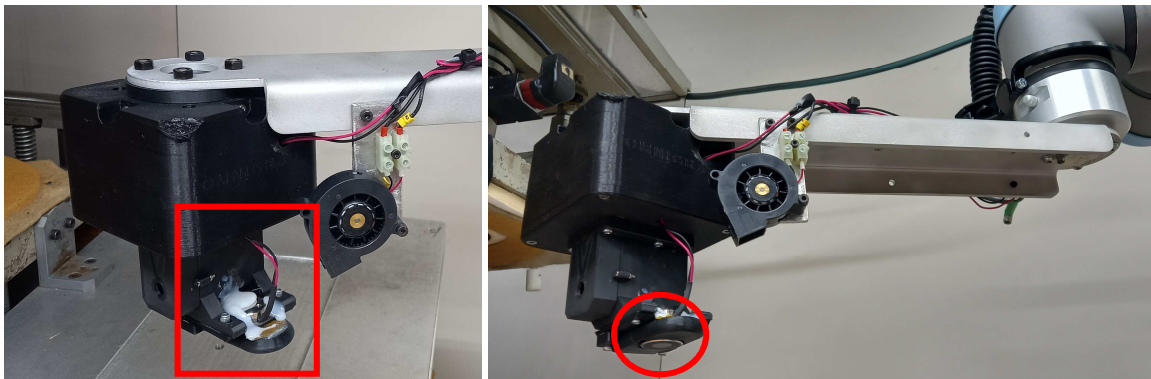


Figure 9. Electromagnet temporary approach.

It has been necessary to calibrate the gripper system (EA gripper or the electromagnet) to the robot, by defining an additional Tool Center Point (TCP) for computing all commands and ensuring the gripper will reach required points. This procedure was done by using the 4-point method from the UR Polyscope interface.

### **Robot mounted cameras**

As it can be seen in Figure 4, Photoneo and IDS camera are parallel mounted between them and with the robot arm.

To be able to use them within the complete cell, we calibrated them. To calibrate the Photoneo, we used a Hand to Eye calibration. To obtain this calibration referenced to robot Joint 3, we marked 16 points (Figure 10).

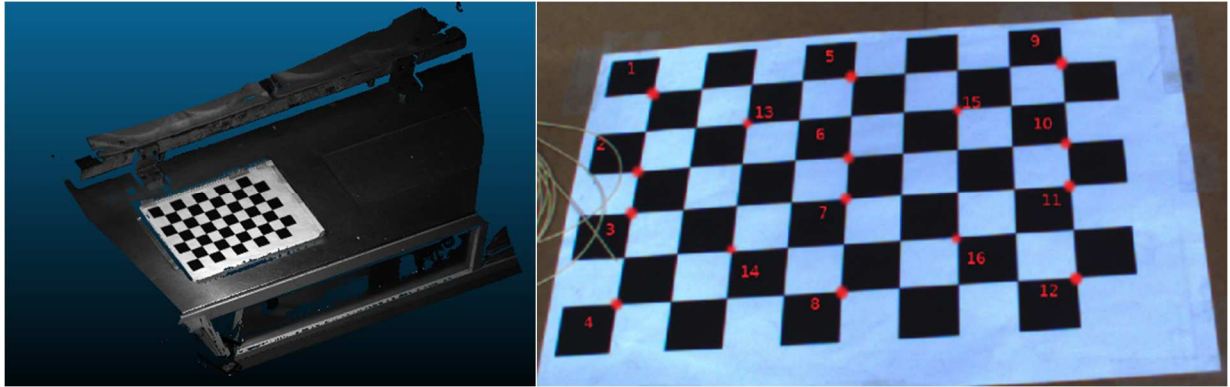


Figure 10. Left: Photoneo pointcloud for calibration. Right: selected points.

Then, to compute the relative position between both cameras, we performed a stereo calibration. In this case, we match points between 3D-data from the Photoneo and 2D image. To evaluate the accuracy of stereo calibration, we coloured the pointcloud that results in Figure 11, with no appreciable error.

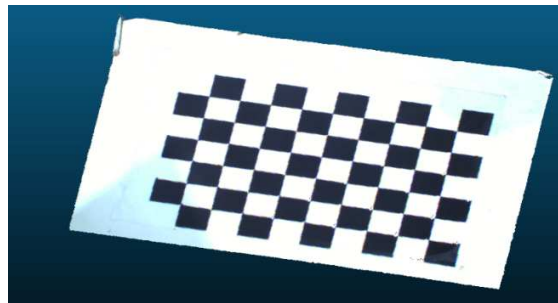


Figure 11. Coloured pointcloud with IDs image and stereo calibration.

### **Blower Fan**

Fan is needed to assure fabric in the quality analysis base. It was integrated on the right robot tool (Figure 4) and connected to a Digital output from the robot to be controlled by ROS commands through Robots Driver (Section 4.5. Robots control of this document).

### **Skills & teaching framework (SPIRE)**

See deliverable 7.2 “Workcell integration – Final version including interfacing”, section 3.2.9 for information.

## 4. Software integration

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### 4.1. Camera drivers

Refer to the deliverable D7.2 “Workcell integration – Final version including interfacing”, section 3.2.3. “IDS camera driver” for information.

### 4.2. Stack fabric detection

Refer to the deliverable D7.2 “Workcell integration – Final version including interfacing”, section 3.2.5. “Stack fabric detection” for information.

Besides, as pointcloud capture position has been modified to AIMEN test conditions, we had to calibrate the press table plane to correctly obtain the fabric to pick from stack.

### 4.3. Speed Separation Module (SSM) and SSM2UR

During the implementation of this use-case, the performance of SSM was lower in the Dell server than it should have been. The underperformance is due to an incompatibility between the CUDA<sup>1</sup> and the UR driver at Linux kernel level<sup>2</sup>. Thus, we took the decision to execute these modules in a Jetson Orin instead of the Dell Server. The Jetson Orin is connected to the IDS cameras through the ethernet switch.

In addition, some issues emerged during the integration of SSM2UR module with the UR robots. The communication with the robot through the /play and /pause services resulted in an error. This could be attributed to a bug in the ROS driver provided by the robot manufacturer. To resolve this problem, we opted to abandon these services in favour of /set\_speed\_slider to set the speed to zero. The anticipated behaviour was achieved. Refer to the deliverable D7.2 “Workcell integration – Final version including interfacing”, section 3.2.7 “SSM2UR” for more information about the operation of these modules.

### 4.4. Cup Quality Control

Refer to the deliverable D7.1 “Report on integration”, section 3.3.2.3 “SELMARK: Cup Quality Control” for information.

To integrate this module in the SELMARK cell, we had to adapt its parameters to the cup-size thermoformed as well as the working plane to boost system performance.

### 4.5. Robots control

Refer to the deliverable D7.2 “Workcell integration – Final version including interfacing”, section 3.2.2. “UR10e robot driver” and 3.2.6. “Picking transforms” for information.

### 4.6. EA Grippers’ driver

Both grippers’ hardware and software requirements could not be fulfilled by the Dell server (not enough USB ports and different ROS version). Therefore, the deployment was done in a barebone PC connected to the server through the ethernet switch.

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<sup>1</sup> <https://forums.developer.nvidia.com/t/build-the-real-time-kernel/229571/3>

<sup>2</sup> [https://github.com/UniversalRobots/Universal\\_Robots\\_ROS\\_Driver/blob/master/ur\\_robot\\_driver/doc/real\\_time.md](https://github.com/UniversalRobots/Universal_Robots_ROS_Driver/blob/master/ur_robot_driver/doc/real_time.md)

#### 4.7. SPIRE

Virtual Reality software requires Windows and some modules based on ROS require Linux, therefore it was necessary to have a PC with Windows and a Linux virtual machine. This PC is connected to the URs through the ethernet switch.

Refer to the deliverable D7.2 “Workcell integration – Final version including interfacing”, section 3.2.9 “Skills & teaching framework (SPIRE)” for information.

#### 4.8. Wrinkles removal package

Refer to the deliverable D7.2 “Workcell integration – Final version including interfacing”, section 3.2.4 “Wrinkles removal package” for information.

Due to the tool’s dimensions, the available list of possible actions to remove this wrinkle was reduced. We discarded those actions, which were closer than a set distance to avoid collisions between robot tools.

#### 4.9. Orchestration Workcell Controller (DOHC)

Refer to the deliverable D7.2 “Workcell integration – Final version including interfacing”, section 3.2.8 for information.


## 5. Testing activities and results

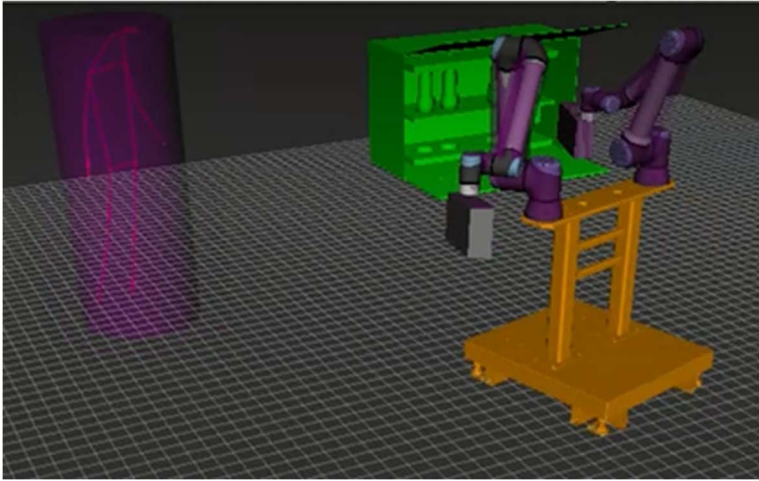
This section discusses the achievements of task T8.1 that involves the delivery of an integrated solution that addresses the challenges of the SELMARK use-case. The aforementioned modules have been integrated towards the successful automation of the thermoforming process. In collaboration with SELMARK, a representative set of activities has been selected, that demonstrates the system's capabilities but also confronts the most important operations from the end-user's perspective. The demonstrated and tested operations, as reported in the submitted video, are summarized in Table 1.

Table 1. Different steps of the handling process evaluated in the integrated demonstration

Sequence number	Name of activity
01	SSM
02	EA Grippers' grasping sequence
03	SPIRE
04	DOHC
05	Fabric stack detection
06	Wrinkles removal
07	Thermoform cups
08	Cup Quality Control

The remainder of this section consists of a supplementary description of the reporting video.

01	SSM
	<ul style="list-style-type: none"> <li>• Bound box around every person in both cameras.</li> <li>• Detection of the position of the body and returns the points that describe it in world's coordinate system.</li> </ul>



- Creation of a cylinder that wraps the person.
- The URDF description and the /joint\_states ROS topic give sufficient information about the shape and movements of the robots.
- SSM workouts the distances between the representation of people and robots.
- Those distances are compared with some thresholds. Then, a message is sent to modify their behaviors (run, slow or stop) for human-robot interaction purposes.
- An intermediate ROS node (SSM2UR) is in charge of taking the SSM output and communicate it to the UR robots.

02

EA Grippers' grasping sequence



- The robots go to the position to apply the electro-adhesion.
- The robots go to the intermediate position to close the finger.



- When the fabric is grasped, the robots bring it to the next position.

03

SPIRE – Motion-capture Teleoperation and replay skills



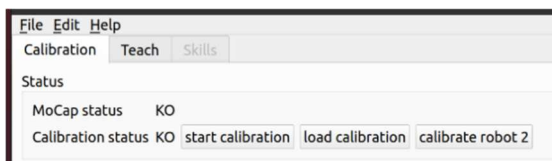
**Installation phase**

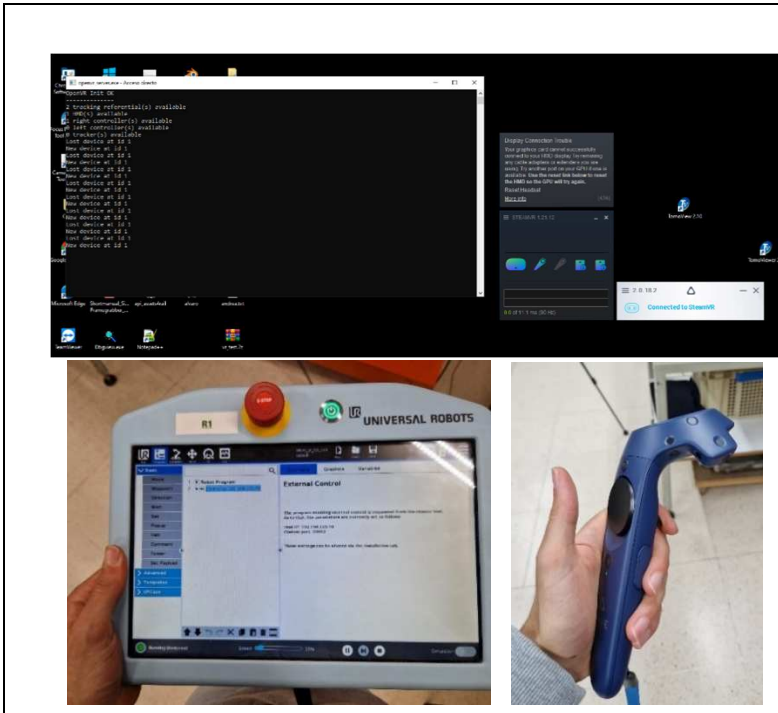
- Installation of the two “light houses”. They should be placed at two corners of the robotic cells to track robot movement during the calibration phase, and to track the user teaching movements.
- Connection of all VR system setup, including the VR helmet, to the VR PC.
- Launch Steam VR on VR PC to ensure all VR elements are visible and working correctly.



**Calibration phase**

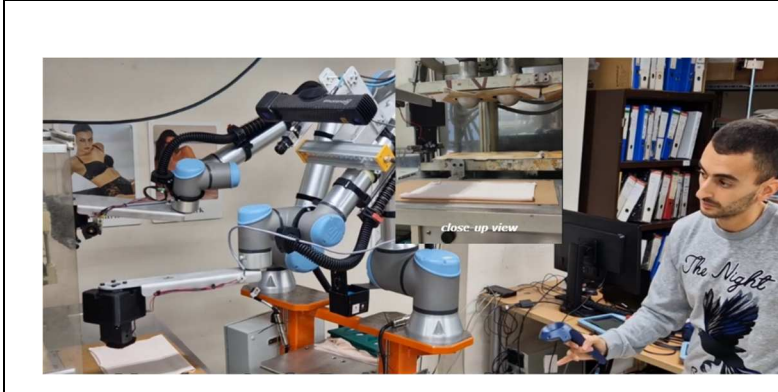
- Calibration must be done each time a light-house is moved.
- Vive tracker is mounted on one robot end-effector
- Calibration is done automatically, with the robot following predefined target points.





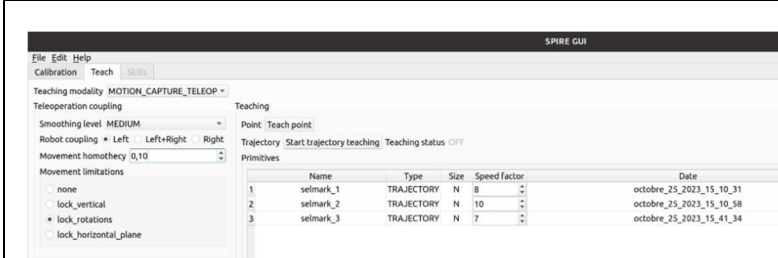
**System control**

- The MoCap server is launched on the VR PC. It allows the VR system to send the remote control coordinates to SPIRE
- SPIRE is launched on the ROS control PC. It uses the MoCap data feed to control the robot.
- On the UR10e, the remote control program is launched, allowing to control the robot via ROS.
- The user operates the robot with the HTC remote control.



**Grasping phase**

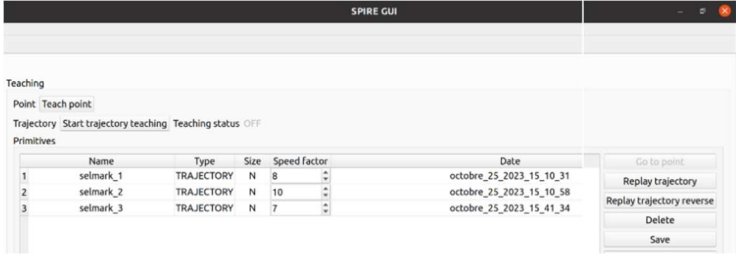
- If the fabric is not already grasped by both robots, grasping has to be done manually.
- User teleoperates one robot at a time to put it in grasping position.
- User activates grippers.



**Teaching phase**

- User teaches trajectories to one or both robots.
- Teaching is recorded only while coupling is active (trigger pressed)
- User can activate any needed assistances, such as movement homothety, and movement limitations (lock rotations, vertical, horizontal plane)





The screenshot shows the SPIRE GUI interface. It includes a 'Teaching' section with 'Point: Teach point' and 'Trajectory: Start trajectory teaching Teaching status: OFF'. Below this is a table of primitives:

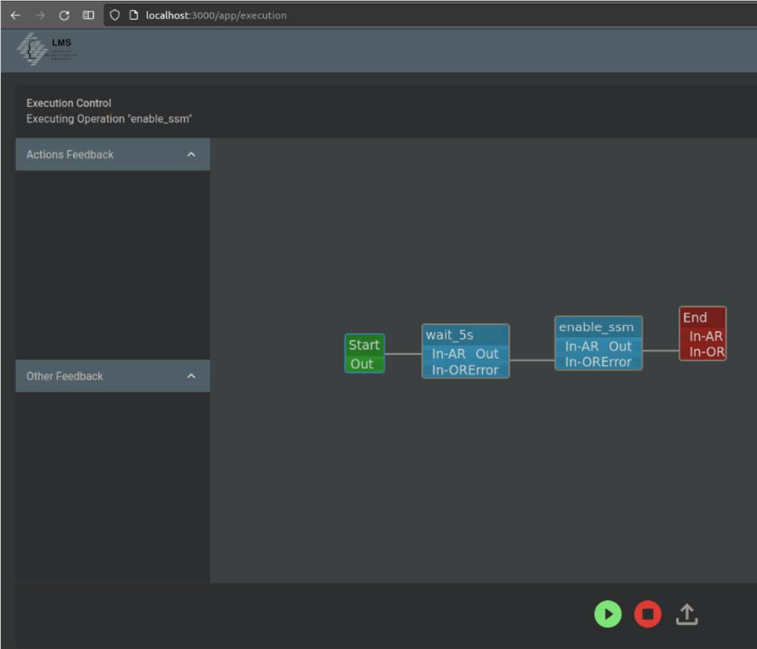
Primitives	Name	Type	Size	Speed factor	Date
1	selmark_1	TRAJECTORY	N	8	octobre_25_2023_15_10_31
2	selmark_2	TRAJECTORY	N	10	octobre_25_2023_15_10_58
3	selmark_3	TRAJECTORY	N	7	octobre_25_2023_15_41_34

Control buttons on the right include: 'Go to point', 'Replay trajectory', 'Replay trajectory reverse', 'Delete', and 'Save'.

**Replay phase**

- Previously recorded trajectories can be replayed using the SPIRE GUI
- Speed factor can be applied to replay faster than recording.

04 DOHC



The screenshot shows the LMS Execution Control interface. It displays 'Executing Operation: enable\_ssm'. A state machine diagram is visible with the following steps:


```

graph LR
    Start[Start] --> wait_5s[wait_5s]
    wait_5s --> enable_ssm[enable_ssm]
    enable_ssm --> End[End]
    
```

Each step in the diagram includes 'In-AR' and 'Out' labels, and the 'enable\_ssm' step also includes 'In-OR' and 'Out' labels. Control buttons at the bottom include a play button, a stop button, and an upload button.

- Several integration tests were performed to control multiples modules of the use-case.

05 Fabric stack detection



The photograph shows a robotic arm in a laboratory setting. The arm is positioned over a table with a fabric stack. A blue arrow labeled 'MERGING' points towards the fabric stack. The text 'Fabric stack localization' is overlaid on the bottom left of the image.

**Fabric stack detection and manipulation:**

- Robot moves to capture position and process a combination of 2D and 3D data.
- Obtain top fabric grasping points.



- Robot moves to points and grasp the fabric to put it inside of the press.

06

Wrinkles removal

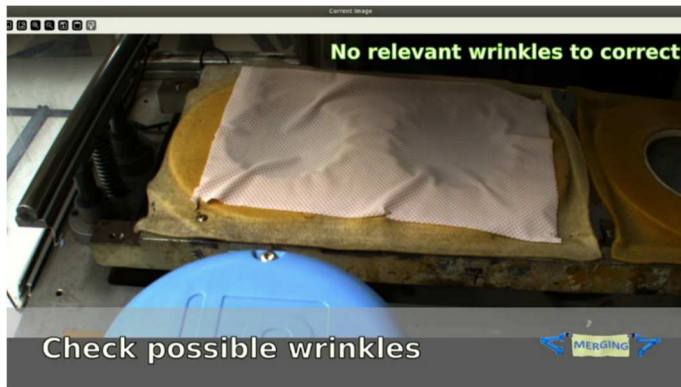
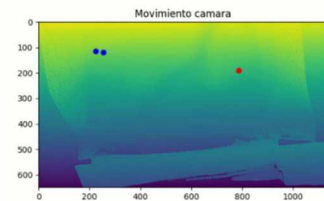


Figure 1



Red: fixed point  
Blue: displacement to perform to remove wrinkle



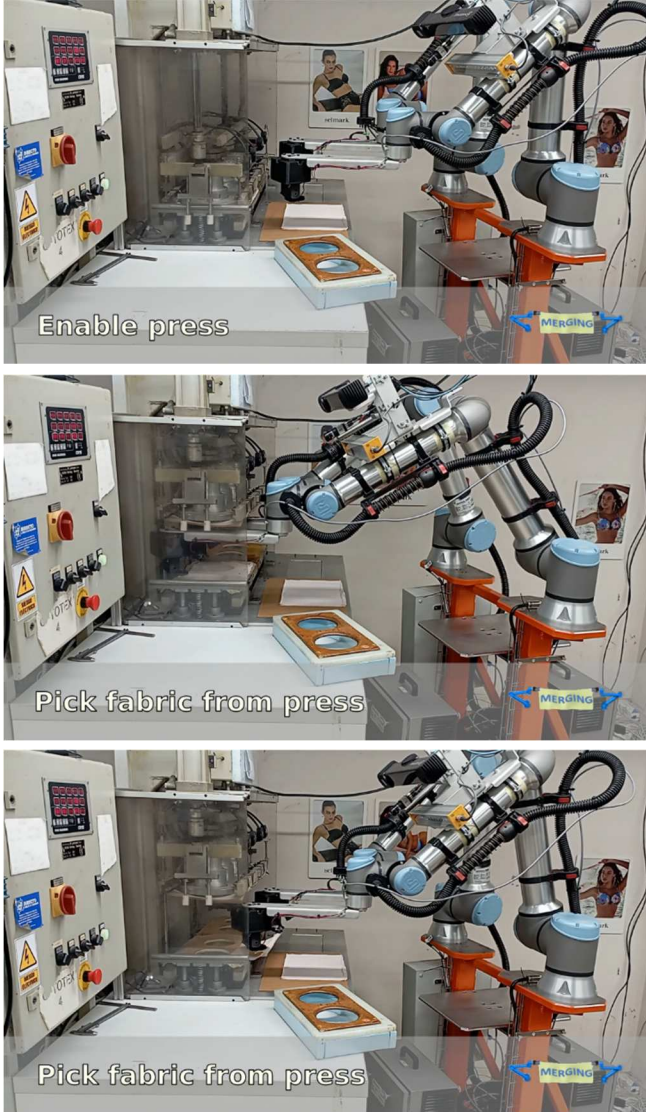
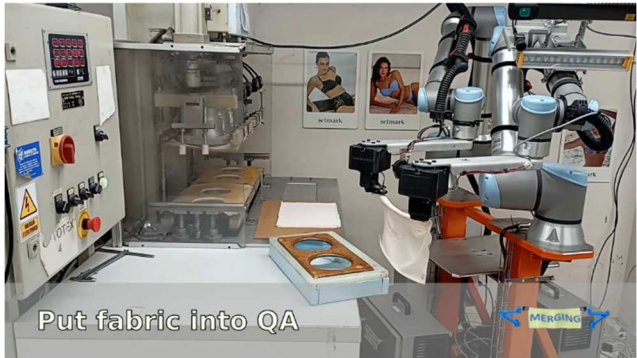
Compute removal action

**Wrinkles removal module:**

- With fabric inside of the press, take a capture of the scene.

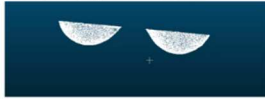
- Fabric segmentation and processing.

- Obtain wrinkle removal action if needed.

07	Thermoform cups	<p><b>Thermoform cups sequence:</b></p> <ul style="list-style-type: none"> <li>• With flat fabric, enable the press by robot signal trigger.</li> <li>• Pick fabric from press.</li> </ul>
 <p>Enable press</p> <p>Pick fabric from press</p> <p>Pick fabric from press</p>		<p><b>Cup QA sequence:</b></p> <ul style="list-style-type: none"> <li>• Put fabric into QA support.</li> </ul>
08	Cup quality control	 <p>Put fabric into QA</p>



Obtained pointcloud



Filtered pointcloud

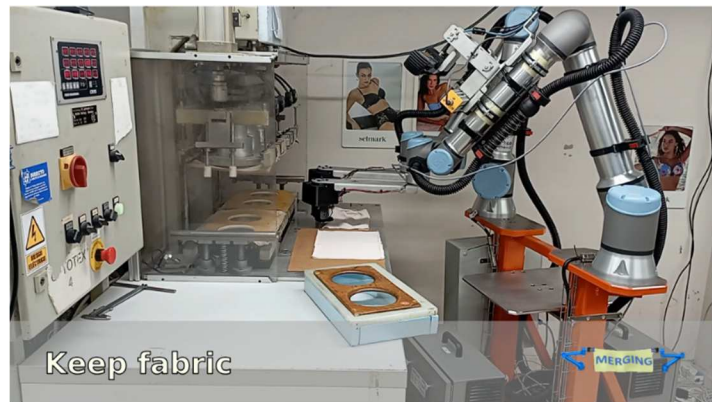


Result

```

# of pts: 42 813
# of vox: 200 200 200
The captured pointcloud is:
[ 0.0171  2.1116  202.2081  -2.1116  200.0172  50.0000  7]
[ 0.0171  2.1116  202.2081  -2.1116  200.0172  50.0000  7]
[ 0.0171  2.1116  202.2081  -2.1116  200.0172  50.0000  7]
[ 0.0171  2.1116  202.2081  -2.1116  200.0172  50.0000  7]
[ 0.0171  2.1116  202.2081  -2.1116  200.0172  50.0000  7]
[ 0.0171  2.1116  202.2081  -2.1116  200.0172  50.0000  7]
[ 0.0171  2.1116  202.2081  -2.1116  200.0172  50.0000  7]
[ 0.0171  2.1116  202.2081  -2.1116  200.0172  50.0000  7]
[ 0.0171  2.1116  202.2081  -2.1116  200.0172  50.0000  7]
[ 0.0171  2.1116  202.2081  -2.1116  200.0172  50.0000  7]
    
```

Cup size is correct



- Capture pointcloud and process.

- If OK, keep fabric.

- If NOT OK, discard fabric.

## 6. Conclusion and next steps

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This report describes the demonstration deliverable that concludes the activities of task T8.1. It discusses the technologies integrated at SELMARK work-cell to perform the MERGING integrated solution. It has visual support from the videos recorded in the end-user facilities to demonstrate the obtained performance of the system.

Next steps involve testing of the solution with technical experts and most importantly with end-user operators. The evaluation activities will be documented in the deliverable D8.4 'Report on Merging robotic technologies assessment'.