ONE4ALL - Agile and modular cyber-physical technologies supported by data-driven digital tools to reinforce manufacturing resilience

Project nr: **101091877**

D4.1 – RCPM specifications, prototype version and tests foreseen

Version:1.0

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ONE4ALL Key Facts

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ONE4ALL Consortium Partners

N.	**Partner**	**Acronym**	**Country**
1	IDENER RESEARCH & DEVELOPMENT (Coordinator)	IDE	ES
2	INNOPHARMA TECHNOLOGY	INO	IE
3	CRIT	CRIT	IT
4	EXELISIS	EXE	GR
5	UNIVERSITY OF SOUTHERN DENMARK	SDU	DEN
6	AUTOMATIONWARE	AUTO	IT
7	MADAMAOLIVA	MOL	IT
8	HOLOSS	HOLO	PT
9	DORTMUND UNIVERSITY	TUDO	DE
10	ORIFARM	ORI	CZ

Disclaimer

Executive Summary

This deliverable (D4.1 - RCPM specifications, prototype version and tests foreseen), is the output of task T4.1 (RCPM specifications, requirements and workplan) which is the first task scheduled for the Work Package WP4 (Innovative reconfigurable cyber-physical production module (RCPM)). This deliverable was completed by AUTO in collaboration with the involved partners.

The aim of this document is to provide the requirements and specifications for RCPM and the definition of the end-user demonstrations proposed in the agri-food sector (MOL) and in the pharmaceutical sector (ORI). These details have been defined with the support of the use-cases and taking into account the project’s purpose to transform manufacturing plants towards Industry 5.0.

In this document is provided an overview about the robotic solutions proposed by AUTO for ONE4ALL project. About the demonstration applications proposed to the end-users, this report provides the general requirements and specifications about the applications, software, hardware tools to be used. Further technical details will be defined according with partners during the next tasks of WP4.

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List of acronyms

RCPM	Reconfigurable Cyber-Physical production Module
IOP	Intelligent Orchestration Platform
J-Actuator	Robotic joint developed by AW
AWTube	6 DOF robotic arm prototype
AWCombo	Robotic composition prototype of one AWTube and one AGV
ROS	Robot Operating System
ECAT	EtherCAT
FSOE	Fail Safe over EtherCAT
RoboVu	Software package which implements EtherCAT Master functionalities and which connects EtherCAT datagram with ROS
AMR	Autonomous Mobile Robots
AGV	Automated/Automatic Guided Vehicle
IOP	Intelligent orchestration platform
DT	Digital Twin
DOF	Degree Of Freedom
PLC	Programmable Logic Controller
PDO	Process Data Object
SDO	Service Data Object
SBC	Safe Brake Control
DTs	Digital Twins
EOL	End Of Line
SKU	Stock Keeping Unit
Cobot	Collaborative Robot
IIOT	Industrial Internet of Things
I5.0	Industry 5.0
DMP	Data Management Plan
WP	Work Packages

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1. Introduction

The ONE4ALL project has a transformative goal of revolutionizing manufacturing plants, particularly those of small and medium-sized enterprises (SMEs), to align with Industry 5.0 (I5.0) principles. The project focuses on enhancing the resilience of these plants to effectively respond to unforeseen social needs by leveraging advanced technologies that prioritize human well-being and sustainability. A key component of this initiative involves the utilization of plug-and-produce reconfigurable cyber-physical production modules (RCPMs). These modules consist of self-reconfigurable mobile robots seamlessly integrated with Industrial Internet of Things (IIoT) devices, enabling real-time monitoring capabilities. The development of RCPMs falls under the WP4 of the project, led by AUTO. This document is the result of the T4.1, "RCPM specifications, requirements and workplan", therefore it will contain the information related to:

- Detailed requirements and specifications of the RCPM.
- Conceptual and initial design of the RCPM, specially focusing on the collaborative cobots.9
- RCPM connection with the Intelligent Orchestration Platform (IOP).
- RCPM applications – demonstration activities.

Which are the key expected results of the task. This deliverable is organized as follows: In the Chapter 2 it is provided an overview of the robotic solutions developed by AUTO, which will be used for the RCPM development in WP4. In Chapter 3, an overview of a first architecture to implement the communication between RCPM and IOP is described. Chapter 4 provides an overview of the rules for collaborative robots. The remaining Chapters refer to the end-user demonstration applications for MOL and ORI including the outcomes and conclusions about the visits to their facilities, the discussions about the possible applications, the related specifications and the next steps to be planned.

1.1. *Detailed requirements and specifications of RCPM*

The general requirements for the RCPM demonstration applications to be installed in MOL and ORI are summarised in this deliverable. These requirements were discussed by AUTO, IDE, INO, MOL and ORI during the period scheduled for T4.1(M1-M5).

Section 2 of this document will present a comprehensive hardware and software architecture for the reconfigurable cyber-physical production modules (RCPMs) in line with the use cases of MOL and ORI. It should be noted that this initial definition may undergo adjustments as the project progresses to ensure the modules' reconfigurability and their alignment with the principles of Industry 5.0 (I5.0), as well as employees' requirements since human centricity is also a key element to address in ONE4ALL project. In this line, this deliverable outlines the current specifications for the end-user applications and RCPM, taking into account the identified needs of each specific use case. As the development of tasks in WP4 progresses, additional technical details related to the use cases will be incorporated into the specifications. By continuously considering these specifications and advancements, the project aims to achieve the desired outcomes and effectively address the requirements of the MOL and ORI use cases.

AUTO, as the proposed robotic solution for the RCPMs, primarily suggests the use of AWCombo, which is a robotic composition of a mobile robot and a robotic arm. In addition to AWCombo, end-effectors, vision systems and sensors (developed by INO and IDE) could be added to implement the applications defined with MOL and ORI. It is important to clarify that RCPM cannot be "reconfigurable" for unlimited applications. Its reconfigurability should be considered for a number of applications and tasks depending on several factors (environmental, mechanical, physics, software, ...). Some application examples are:

- The usage of a changing tool flange to change the end-effector for executing different tasks improving the efficiency of the application;
- Employ the same mobile robot for executing different tasks in different stations of the production lines, moving the robots from a station to another one.

Thus, the ONE4ALL robotic system, including RCPM, needs to be designed properly according to the application requirements. These requirements shall also consider the technical feasibility and, as stated before, the workforce needs in each application. Therefore, the general approach proposed by AUTO for WP4 is to define the technical specifications for RCPM correlated to the end-user applications defining feasible solutions according to end-users' requirements and the technical factors.

1.2. Key parameters to be monitored

For the correct implementation and monitoring of the technological solutions, some Key Parameters (KP) must be tracked. Some of these (Table 1) were already introduced in the Grant Agreement (GA). As can be observed there are some KPs that are unique and related to the specific activities of each use case (Olive's detection, improvement of palletizing tasks, etc.) activities. It is important to note that as the project develops, the measurement strategy to be used for each key parameter will be defined with each partner. These KP have relation with the KPIs already defined in D7.1 (refer to this document for more details) since they also have information about the performance of the solutions implemented. In T4.2 there will be identified the sensors required to monitor those parameters, as well as identify any lack of monitoring devices within the RCPM. Additionally, an alignment with the quality checks of the products to be identified and characterised in T2.2 will be required. In conclusion, the list of key parameters presented in Table 1 are preliminary and will be further extended during T4.2 and advances of connected tasks. A detailed description of all the parameters monitored and how will be presented in deliverable D4.2 which focuses on IIOT devices based real-time monitoring system.

Table 1. Use-cases Key Parameters

Use-Case	Key Parameters
Madama Oliva	Defect olives detected and discarded
	Working time
	Detection time
	Product quality
	Inspection efficiency
	Saving time and costs
	Saves in resources
Orifarm	Working time
	Storage efficiency
	Response rate
	Improvement of palletizing tasks
	Energy efficiency
	Saving time and costs
	Production rate

2. Overview about RCPM

In this section the proposed robotic solution will be outlined. AutomationWare proposes to use AWCombo to implement the robotic part of RCPM. AWCombo is a robotic composition prototype consisting of different elements which components are going to be further explained from both the software and hardware point of view in the following sections. This device will serve as the starting point from AUTO side for the development of ONE4ALL technologies. To start with, the AWCombo can be divided into two main elements:

- One 6 Degree of Freedom (DOF) robotic arm prototype called AWTube (Section 2.1). It consists of 6 J-Actuators (section 2.1.1) combined in different sizes according to the application requirements. This component can be observed in Figure 1.

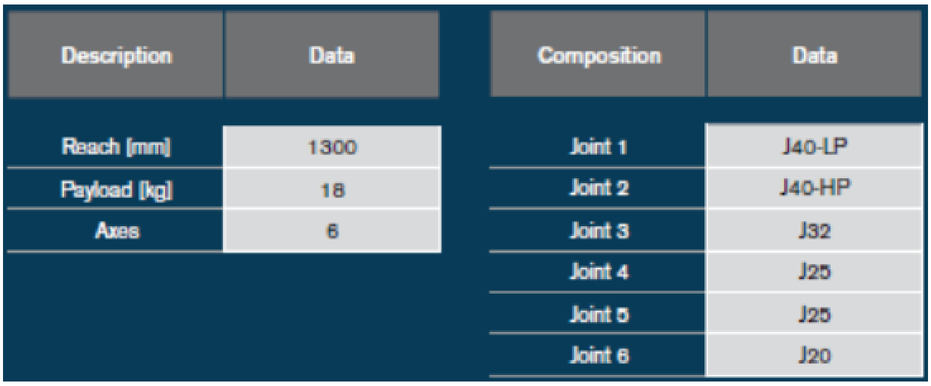
Figure 1: AWTube

- One Mobile Base, which is an Autonomous Mobile Robot (AMR) (Section 2.2), displayed in Figure 2, equipped with 4 omnidirectional wheels.

Figure 2: RCPM Autonomous Mobile Robot (AMR)

2.1. AWTube

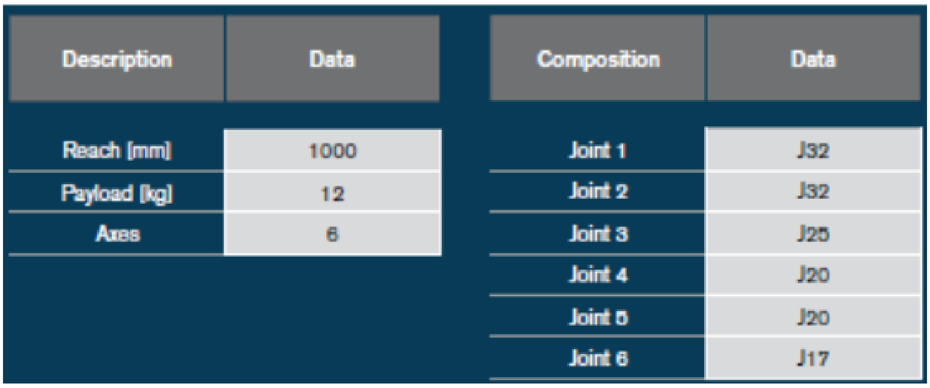
As sates before, the AWTube is a 6 DOF robotic arm which is a composition of 6 J-Actuators with different sizes. Currently, 3 standard sizes for AWTube are available, whose details are further represented in Figure 3, Figure 4, and Figure 5.



Description	Data
Reach [mm]	1300
Payload [kg]	18
Axes	6

Composition	Data
Joint 1	J40-LP
Joint 2	J40-HP
Joint 3	J32
Joint 4	J25
Joint 5	J25
Joint 6	J20

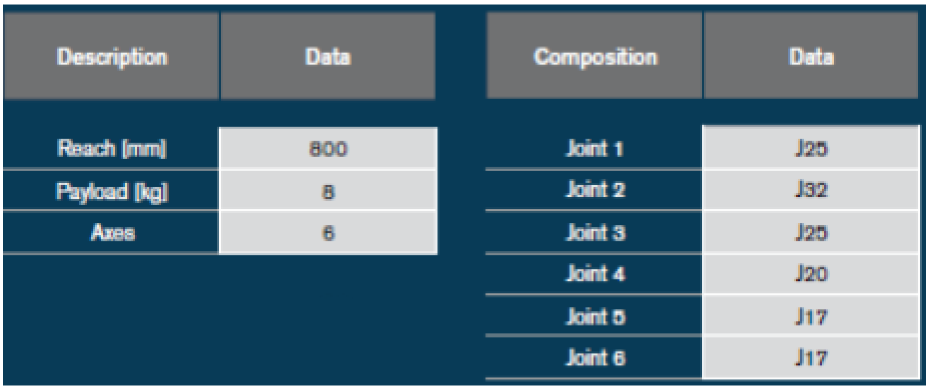
Figure 3: AWTube "L Size" specifications



Description	Data
Reach [mm]	1000
Payload [kg]	12
Axes	6

Composition	Data
Joint 1	J32
Joint 2	J32
Joint 3	J25
Joint 4	J20
Joint 5	J20
Joint 6	J17

Figure 4: AWTube "M Size" specifications



Description	Data
Reach [mm]	800
Payload [kg]	8
Axes	6

Composition	Data
Joint 1	J25
Joint 2	J32
Joint 3	J25
Joint 4	J20
Joint 5	J17
Joint 6	J17

Figure 5: AWTube “S Size” specifications

AWTube was thought to be modular and flexible to better fit the end-user applications requirements. A circuitry including Safety PLC, power suppliers, sensors and IO couplers is provided for each AWTube. In AWCombo this circuitry is integrated in the mobile base (Section 2.2).

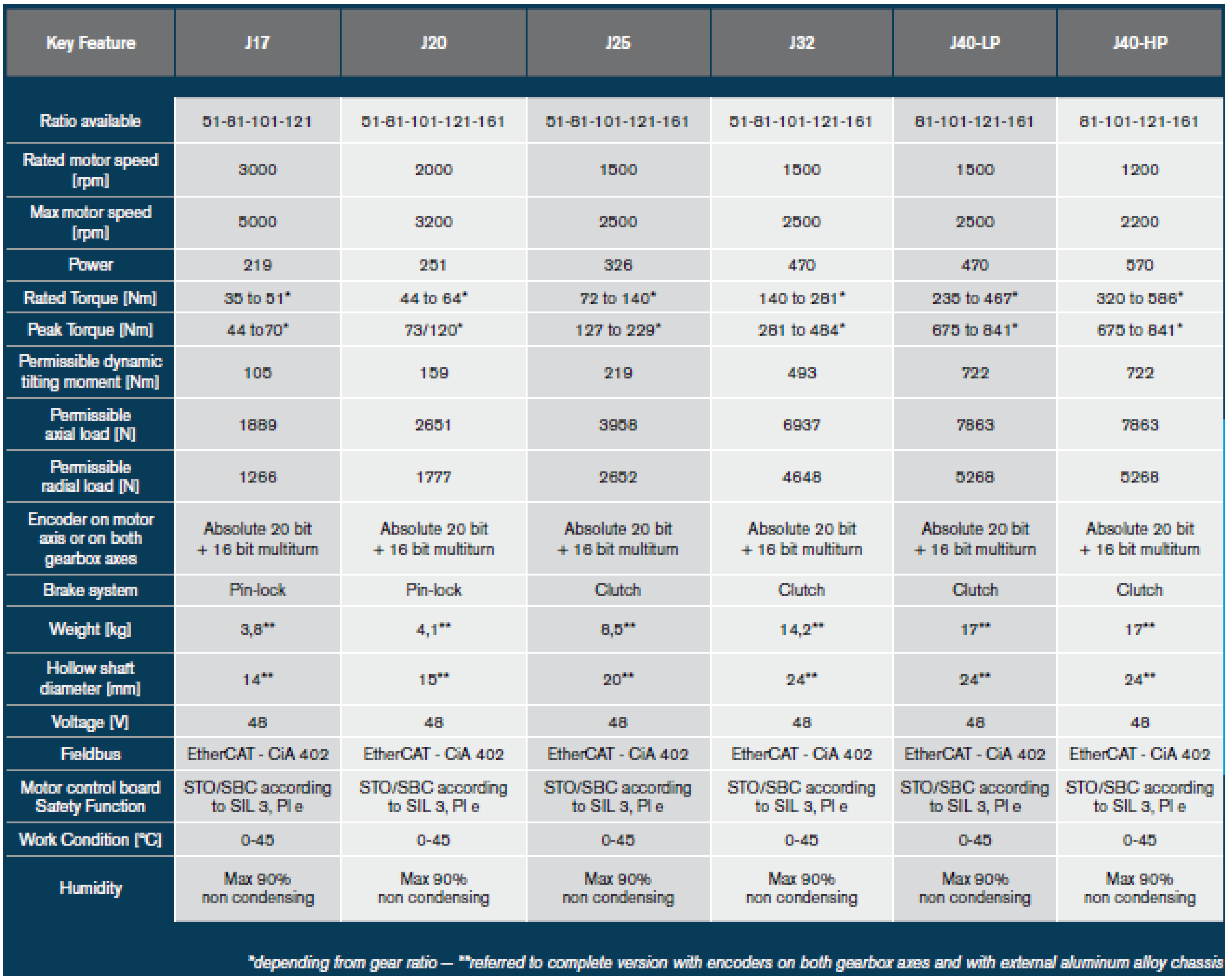
2.1.1. J-Actuator

The "J-Actuator" is a rotary actuator with an integrated electronic motor control board. Its aspect can be observed in Figure 6. It consists of:

- A permanent magnet synchronous motor of the "torque" type at 48 V.
- A harmonic gearbox.
- A holding brake.
- An absolute encoder on the motor shaft.
- Optionally, a second absolute encoder mounted on the gearbox output shaft.
- Integrated motor control board equipped with EtherCAT fieldbus and STO/SBC SIL3 PI-e safety functions.

Figure 6: J-Actuator

J-Actuator is available in different sizes, with different reduction ratios and motor windings so that the actuator can be customized for each required application in terms of output torque, speed and power consumption. The different possible specifications of the actuator are gathered in Figure 7.



Key Feature	J17	J20	J25	J32	J40-LP	J40-HP
Ratio available	51-81-101-121	51-81-101-121-161	51-81-101-121-161	51-81-101-121-161	81-101-121-161	81-101-121-161
Rated motor speed [rpm]	3000	2000	1500	1500	1500	1200
Max motor speed [rpm]	5000	3200	2500	2500	2500	2200
Power	219	251	326	470	470	570
Rated Torque [Nm]	35 to 51*	44 to 64*	72 to 140*	140 to 281*	235 to 467*	320 to 586*
Peak Torque [Nm]	44 to70*	73/120*	127 to 229*	281 to 484*	675 to 841*	675 to 841*
Permissible dynamic tilting moment [Nm]	105	159	219	493	722	722
Permissible axial load [N]	1889	2651	3958	6937	7863	7863
Permissible radial load [N]	1266	1777	2652	4648	5268	5268
Encoder on motor axis or on both gearbox axes	Absolute 20 bit + 16 bit multiturn	Absolute 20 bit + 16 bit multiturn	Absolute 20 bit + 16 bit multiturn	Absolute 20 bit + 16 bit multiturn	Absolute 20 bit + 16 bit multiturn	Absolute 20 bit + 16 bit multiturn
Brake system	Pin-lock	Pin-lock	Clutch	Clutch	Clutch	Clutch
Weight [kg]	3,8**	4,1**	8,5**	14,2**	17**	17**
Hollow shaft diameter [mm]	14**	15**	20**	24**	24**	24**
Voltage [V]	48	48	48	48	48	48
Fieldbus	EtherCAT - CiA 402	EtherCAT - CiA 402	EtherCAT - CiA 402	EtherCAT - CiA 402	EtherCAT - CiA 402	EtherCAT - CiA 402
Motor control board Safety Function	STO/SBC according to SIL 3, Pl e	STO/SBC according to SIL 3, Pl e	STO/SBC according to SIL 3, Pl e	STO/SBC according to SIL 3, Pl e	STO/SBC according to SIL 3, Pl e	STO/SBC according to SIL 3, Pl e
Work Condition [°C]	0-45	0-45	0-45	0-45	0-45	0-45
Humidity	Max 90% non condensing	Max 90% non condensing	Max 90% non condensing	Max 90% non condensing	Max 90% non condensing	Max 90% non condensing

*depending from gear ratio — **referred to complete version with encoders on both gearbox axes and with external aluminum alloy chassis

Figure 7: J-Actuator main specifications

2.1.1.1. Hardware control specifications

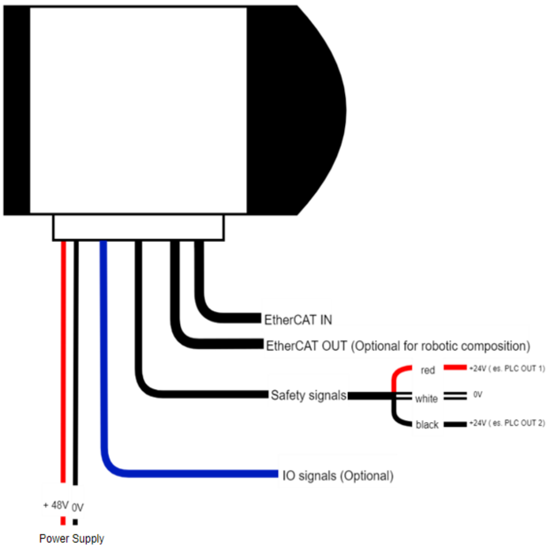


Figure 8: J-Actuator wiring

Each J-Actuator is equipped with a motor control board which implements the EtherCAT[1] Slave functionality in a network based on the EtherCAT industrial field bus. To work, it needs to be connected to an EtherCAT Master, a safety system e.g. PLC and to the power supply.

The motor control board uses two absolute encoders as position/speed sensors, both 16-bit multi-turn and 20-bit single-turn, the first connected directly to the motor shaft (fast shaft) while the second is connected to the output shaft after the gearbox (slow shaft). The board can manage these encoders in both multi-turn and single-turn mode. The encoder configuration is performed during production by Automationware.

The control board controls an electro-mechanical braking system with the Safe Brake Control (SBC) safety feature. Concerning the wiring details, each J-Actuator is equipped with the cabling shown in the Figure 8.

2.1.1.2. Communication protocols

From a communication point of view each J-Actuator acts as an EtherCAT Slave according to EtherCAT and CiA402[2] standards. It exchanges information with an EtherCAT Master device cyclically with a frequency of 1 KHz. The information is stored in datagrams which are composed by Process Data Objects (PDO), each datagram is sent by an EtherCAT Master to each EtherCAT device connected in the same network (EtherCAT Slave) each millisecond. J-Actuator reads data from PDOs sent by the EtherCAT Master device and writes its response in it "on the fly". The information exchanged between EtherCAT Master and EtherCAT Slaves are mapped in TXPDO (from Slaves to Master) and in RXPDO (from Master to Slaves) according to the default mapping shown in Table 2 and Table 3 correspondingly.

Table 2: TXPDO mapping

Index (Object dictionary)	Field name	No. of bit
0x6041	Statusword	16
0x6061	Modes of operation display	8
0x6064	Position actual value	32
0x606C	Velocity actual value	32
0x6077	Torque actual value	16
0x2401	Analog input 1	16
0x2402	Analog input 2	16
0x2403	Analog input 3	16
0x2404	Analog input 4	16
0x2702	Tuning status	32
0x60FD	Digital inputs	32

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[1] https://www.ethercat.org/en/technology.html

[2] https://www.can-cia.org/can-knowledge/canopen/cia402/

Table 3: RXPDO mapping

Index (Object dictionary)	Field name	No. of bit
0x6040	Controword	16
0x6060	Modes of operation	8
0x6071	Target torque	16
0x607A	Target position	32
0x60FF	Target velocity	32
0x60B2	Torque offset	16
0x2701	Tuning command	32
0x60FE:1	Digital outputs: Physical outputs	32
0x60FE:2	Digital outputs: Bit mask	32
0x2703	User MOSI	32
0x60B1	Velocity offset	32

This implies that each millisecond the actual position, speed and torque measured by each J-Actuator can be known by the corresponding EtherCAT Master and by the IOP giving them the possibility to analyse data and planning the next movement for the robotic system. These mapping schemes can be further adapted by AUTO as the activities of WP4 advance, to better fit the requirements of the demonstration applications, according with the other partners.

There are several ways to control J-Actuators or a robotic composition of them. These ways are called "**operation modes**" according with CiA402 standard. The motor control board supports different modes of operation using either an internal trajectory controller (Profile modes) or needing to receive a point-by-point trajectory from a master device (Cyclic modes). A Homing mode is also available to return the motor to a specific position.

Cyclic modes: in cyclic synchronous modes, the trajectory must be calculated by the master and sent to the slave at 1ms intervals.

- Cyclic synchronous torque (CST): in torque control mode, the master sends the desired torques to the drive.
- Cyclic synchronous velocity (CSV): in speed control mode, the master sends the desired speeds to the drive.
- Cyclic synchronous position (CSP): in position control mode, the master sends the desired positions to the drive.

Profile modes: in profile modes, the trajectory is calculated directly by the slave, the task of the master is to command only the desired end reference.

- Profile position (PP): in profile position mode, the trajectory to the target position is generated by the drive, which communicates the outcome of the movement as feedback.
- Profile velocity (PV): in profile velocity mode, the motor rotates at a target speed.
- Profile torque (PT): in profile torque mode, the drive delivers a current to the motor to reach a target torque value.

Homing mode: homing can be used to centre the motor on its current position or to move to a specific position (saved directly in the control board).

All of the above modes comply with the CiA402 standard.

By default, AUTO uses CSP as default operation mode to control J-Actuators or a robotic composition of them. The definition of which operation mode to be used in the demonstration applications for WP4 will be defined by AUTO with partners during the next steps of WP4.

The current versions J-Actuator do not support Safety over EtherCAT (FSOE)[3]. However, AUTO is currently testing a new release of J-Actuator equipped with a motor control board which acts both as EtherCAT Slave and FSOE Slave simultaneously. This version is a prototype at the moment, but it will become a commercial one soon. For these reasons it could be used for the AWCombo units which will be involved in ONE4ALL. As described in the next chapters, FSOE is strictly related to the implementation of collaborative functionalities for robots.

2.2. Mobile base

As mobile base we means an omnidirectional AMR. This AMR is composed by 4 omnidirectional wheels. Omnidirectional wheels, also known as holonomic wheels, are a type of wheel design that enables movement in any direction without the need for traditional steering mechanisms. Unlike conventional wheels that only allow movement in a straight line or require steering to change direction, omnidirectional wheels offer enhanced manoeuvrability and versatility. The wheels are equipped with LIDAR sensors and managed by a software navigation system based on odometry and field scanning. The drivers for the wheels uses Canbus communication protocol[4].

2.3. AWCombo

AWCombo is the combination of the two components explained above, it consists in a composition of a “L size” AWTube and a Mobile Base. The resulting robot is a mobile robotic arm which can be used to execute different tasks (eg. pick&place, palletizing, …) in different points of a production site. It was designed to be used in indoor environments with dry and flat floor conditions. The aspect of the AWCombo is shown in Figure 9. The main features of AWCombo are:

- Omnidirectional AMR.
- 6 axes robotic arm, 18kg payload and 1300mm reach.
- Navigation system based on odometry and field scanning.
- Embedded Safety systems.
- LED indicators.
- Embedded vacuum pump.
- 48 Vdc battery.
- Availability of high-speed inductive charging station.
- Vision system based on Intel Realsense.
- ROS driven.

Figure 9: AWCombo

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[3] https://www.ethercat.org/en/safety.html

[4] https://www.typhoon-hil.com/documentation/typhoon-hil-software-manual/References/can_bus_protocol.html

A circuitry system, which is represented in Figure 10, is embedded on the mobile base to electrically manage both mobile base and robotic arm.

The "**End Effector**" is an optional block which can be defined and integrated according to the specific application requirements. It can be a tool internally designed by AUTO or a commercial one.

The "**Master PC**" refers to an embedded computer mounted in the Mobile Base which manages both the Mobile Base and the AWTube receiving commands from an external "**Application PC**" and sending feedbacks to it.

As stated before, for the project ONE4ALL, AUTO will design AWCombo starting from the current concept of prototype version described in these subchapters.

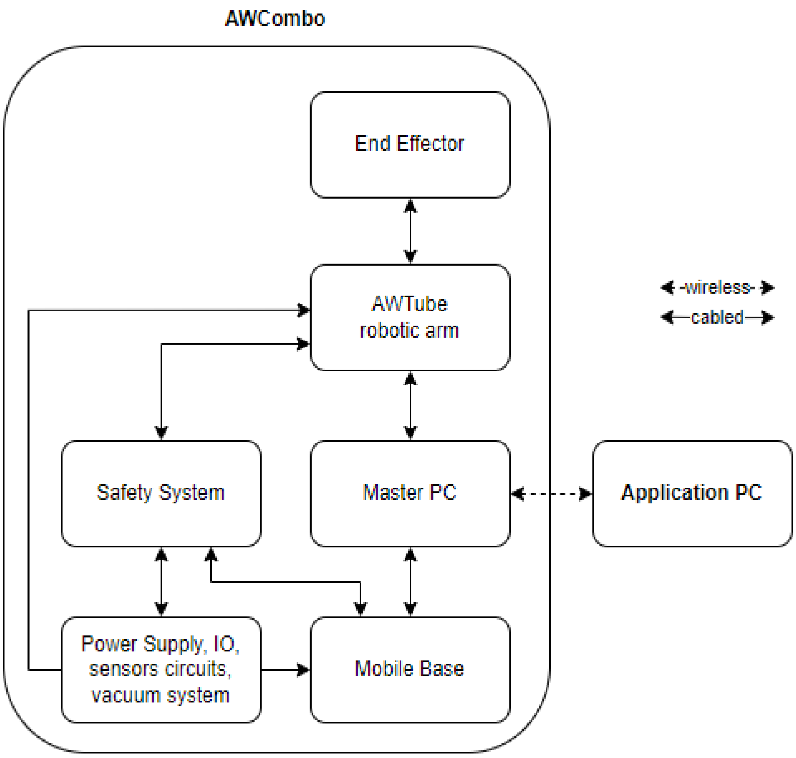

Figure 10: AWCombo Logic Architecture

2.4. RoboVu and Software Architecture

AUTO developed a software architecture based on Robot Operating System (ROS or ROS2) to manage their robotic arms (AWTube) and robotic joints (J-Actuator). ROS is an open-source framework which allow users to implement software to manage robotic systems.

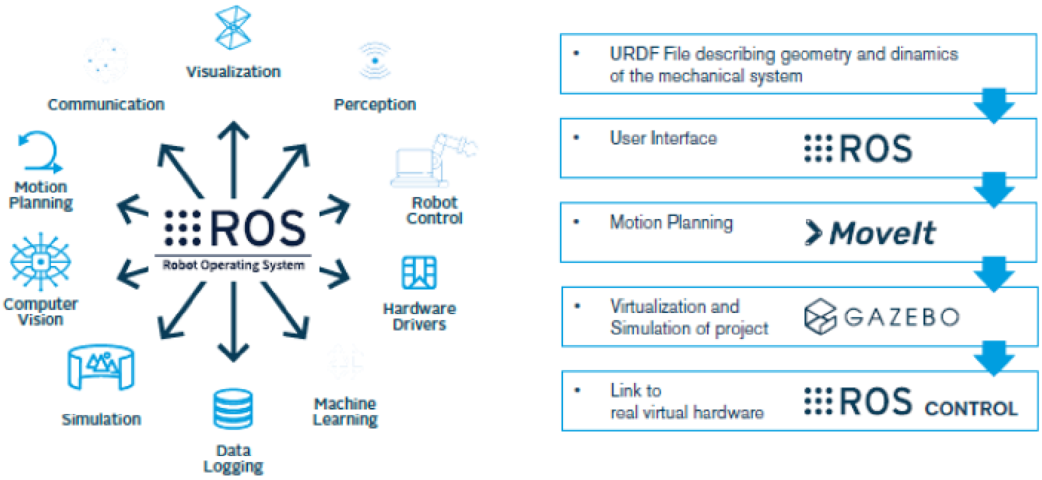

Figure 11: Robotic Operating System overview

Motion Planning functionalities are implemented in ROS using the framework MoveIt[5] which offers several planning solutions allowing the users to select the best one to fit their requirements. Motion planning algorithms available on MoveIt fit the URDF model derived from the CAD project.

Using Gazebo[6] it is possible to reproduce a robotic cell and testing it in a virtual environment. This can be very useful during the initial stages of a project to do an accurate feasibility study of the application taking any countermeasure in a preventive way.Safety is implemented outside ROS, using proper commercial devices (SAFETY PLC). Furthermore, as explained in section 2.1.1.2, soon it will be possible to manage J-Actuators and AWTube arms using Fail Safe Over EtherCAT (FSOE) to separately exchange «non fail safe» data from the «fail safe» ones.

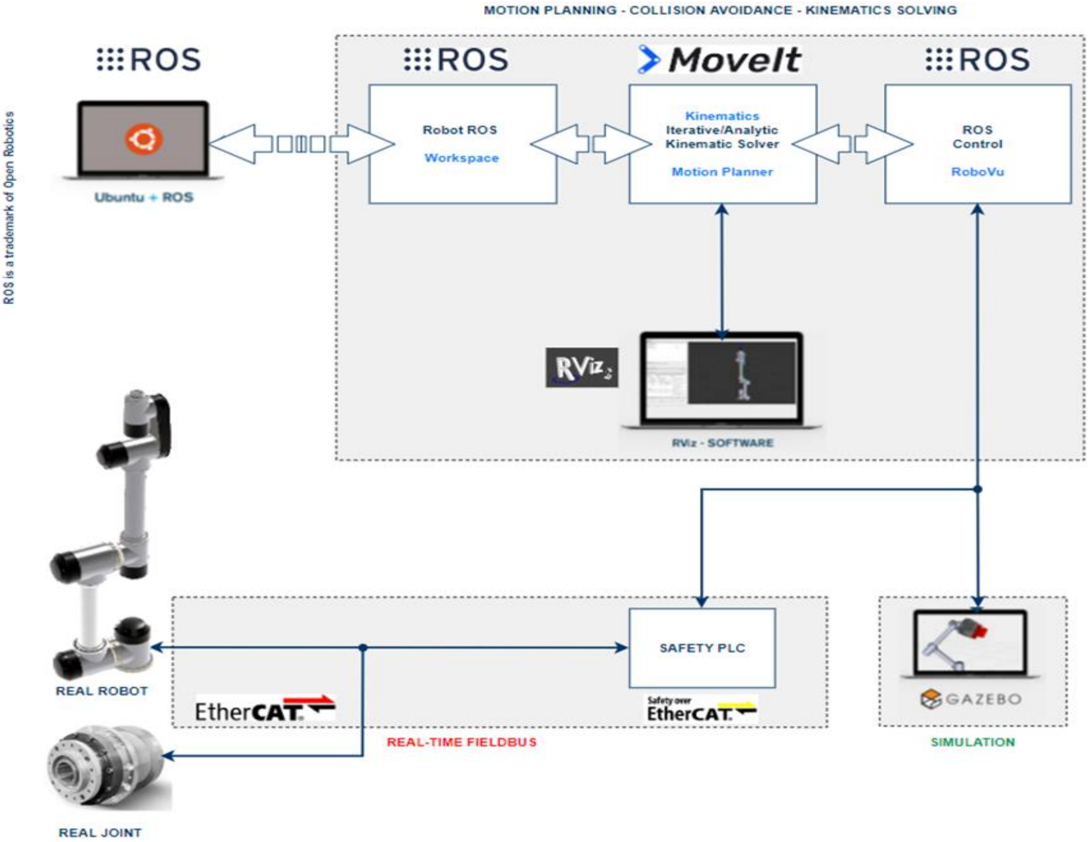

Figure 12: AW Software Architecture

RoboVu is a prototype software interface to connect ROS/ROS2 with EtherCAT driven actuators. A schematic of the softwere and connections can be observed in Figure 13. Some details about RoboVu are:

- It translates the motion information planned by ROS in EtherCAT datagrams to manage EtherCAT drivers.
- It was developed by AutomationWare in collaboration with Fraunhofer Italia.
- RoboVu implements EtherCAT Master functionalities using the Simple Open EtherCAT Master Library (SOEM) on the computer in which it is running.
- It runs on ROS/ROS2 installed in a Linux Ubuntu OS equipped with a «RT Patch» to allow “soft-realtime” performances.

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[5] https://moveit.ros.org/

[6] https://gazebosim.org/home

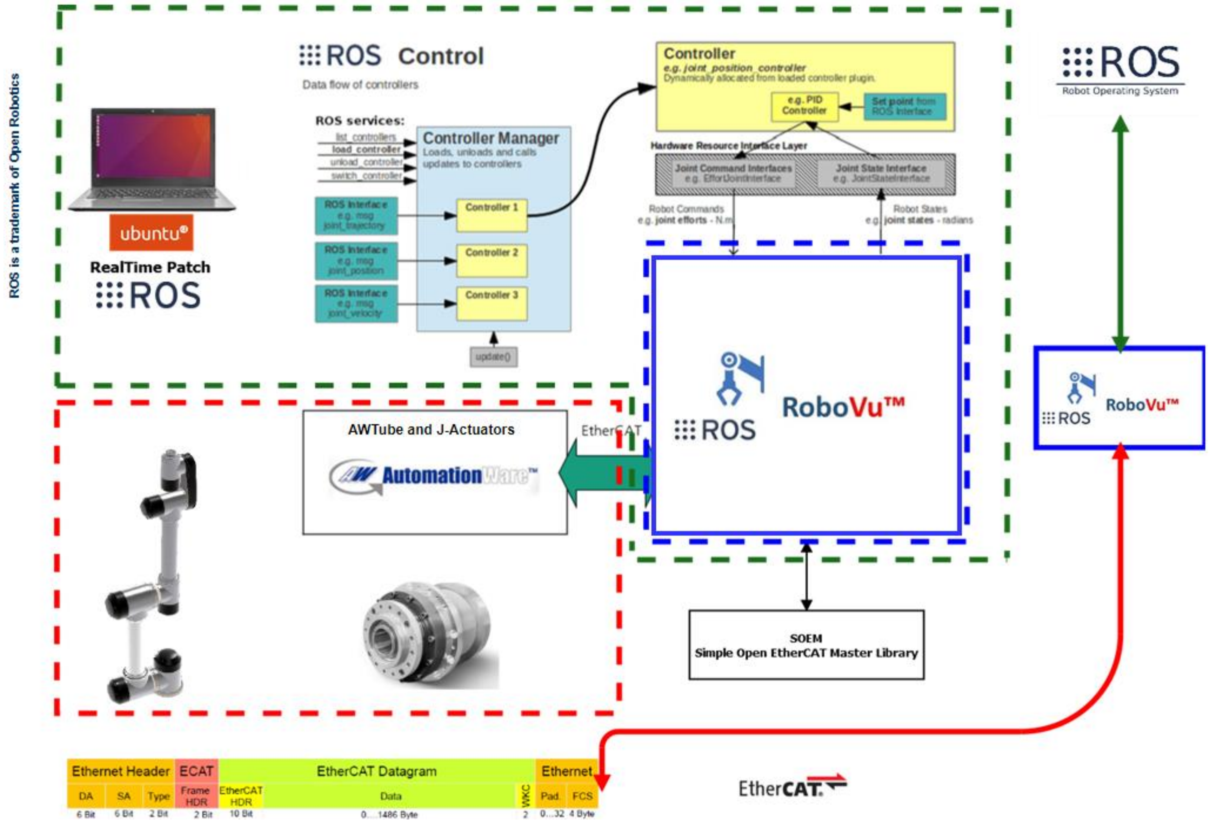


Figure 13: RoboVu scheme in practice

The current version of RoboVu provides “soft-real time” performances and it is not compatible for FSOE management. According to the software architecture described in this subchapter it is possible to manage also AWCombo

Using a single hardware (“Master PC”) it is possible to manage “Mobile Base” and “AWTube” using proper ROS packages (eg. ROS2 “movebase” and “movegroup” actions). This modularity is one of the key features of ROS; in fact, it is possible to control different robots or mechatronics devices using a unique Motion Planning.

For the project ONE4ALL, AUTO is studying and evaluating also an alternative EtherCAT Master to RoboVu to allow the interoperability of the EtherCAT Master with FSOE network.

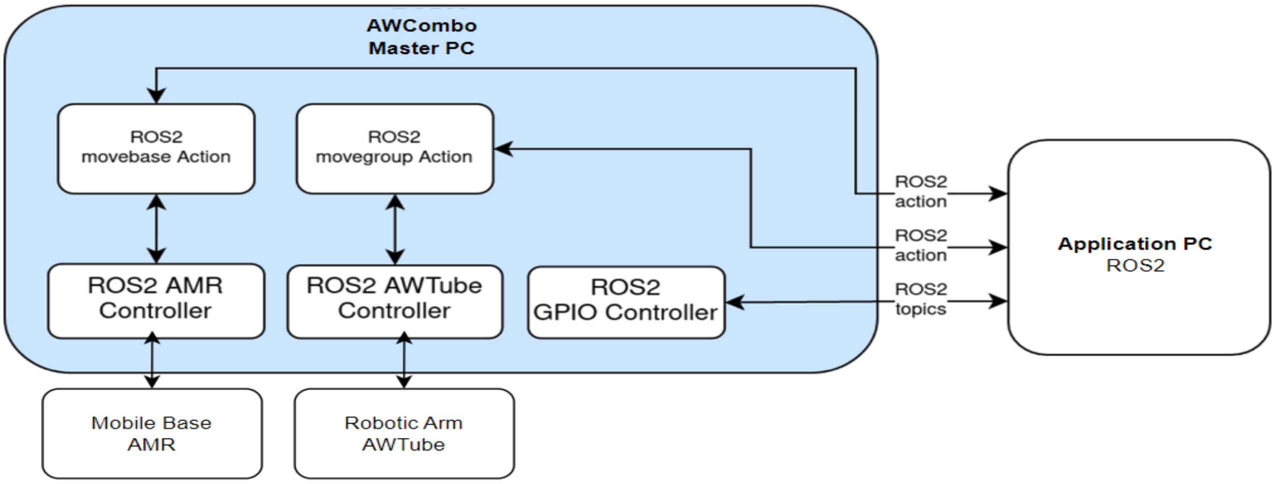


Figure 14- AWCombo Software Overview

3. Overview about the communication between RCPM and IOP

ROS (Robot Operating System) is a flexible and powerful framework for building robotic systems, providing tools and libraries for developing, controlling, and integrating robots and their components. In the context of the IOP, ROS serves as a bridge between the RCPM module and other platform components, enabling seamless communication and data exchange. To facilitate this integration, we will utilize specific libraries and technologies within the ROS ecosystem, such as rospy (ROS1) or rclpy (ROS2) for Python-based ROS development.

3.1. Integration in the IOP

ROS plays a vital role in the IOP architecture by facilitating real-time control and monitoring of robots and their performance. It enables the RCPM module to publish messages containing control commands or performance data, while other components of the IOP can subscribe to these messages and extract relevant information for further processing or analysis. This communication is established through the use of ROS topics and the associated message-passing mechanism.

In the modular IOP architecture, the ROS node can be integrated into different layers depending on the specific requirements and functionalities of the system. For example, the ROS node can be included in the data ingestion layer, the real-time processing layer, or the serving layer.

- In the data ingestion layer, the ROS node acts as a bridge between the RCPM module and the data ingestion components of the IOP. It receives performance data or control commands from the RCPM module, packages them into ROS messages, and publishes them on relevant ROS topics. These messages containing the data can then be subscribed to by other components within the IOP, allowing them to extract and process the information for further analysis or storage.
- In the real-time processing layer, the ROS node enables the integration of the RCPM module with real-time data processing algorithms or decision-making components within the IOP. The ROS node subscribes to relevant ROS topics where real-time data is published, such as sensor data or control commands from other modules. It extracts the required data from these messages and provides it to the real-time processing components for immediate analysis, decision-making, or feedback generation.
- In the serving layer, the ROS node contributes to delivering insights, reports, or visualizations derived from the processed data to end-users or other systems. It may receive requests for specific information from other components or external entities, and based on these requests, the ROS node retrieves the necessary data from the ROS topics or storage systems. The node then processes the data and delivers the requested information in a consumable format.

The development of the ROS node within the modular IOP architecture follows a modular approach. Each component of the IOP, including the RCPM module and the ROS node, is developed independently but with a clear understanding of the interfaces and communication protocols required for seamless integration. This modular development allows for easy maintenance, scalability, and reusability of components within the IOP ecosystem.

The ROS node can be developed using ROS-specific libraries and tools, such as rospy and rclpy in Python, which provides an interface to interact with ROS functionalities. Additionally, the modular IOP architecture promotes code reuse and collaboration, allowing developers to leverage existing ROS packages and contribute their own, fostering a vibrant community of robot developers within the IOP ecosystem.

3.1.1. RCPM – IOP

The following block diagram (Figure 15) provides an overview about the communication between RCPM, IOP and Data-Driven DTs:

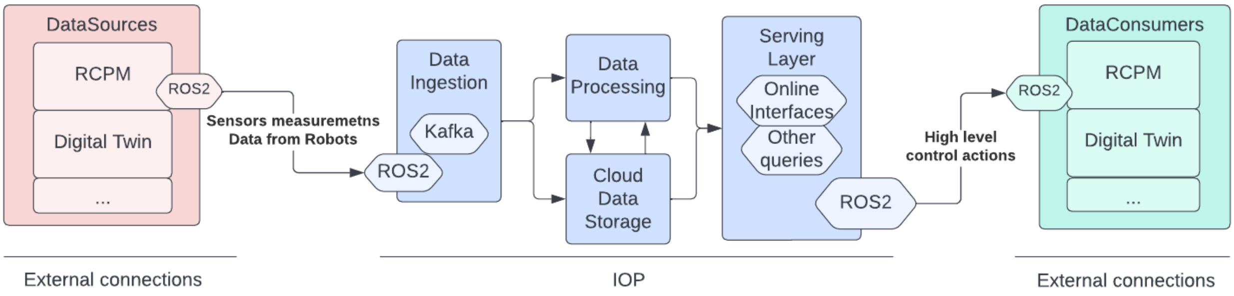


Figure 15: Overview diagram of RCPM - DTs - IOP connections

The term "Robots" refers to the physical robot provided by AW (RCPM), while "ROS modules" refers to the ROS2 modules integrated in both IOP and RCPM for information exchange.

The Intelligent Orchestration Platform (IOP) will be implemented and managed by IDE. It serves as the intermediary connecting the Data-Driven Environment, implemented by SDU, with the RCPM provided by AUTO.

There are several methods available for communication with ROS2:

- ROS2 Interfaces: ROS applications commonly communicate through three types of interfaces: messages, services, and actions.
- ROS2 Client Libraries: These libraries provide APIs that enable users to implement their own ROS code. By utilizing client libraries, users can access ROS concepts such as nodes, topics, services, and more.
- rosbridge_suite: This suite offers a JSON API for non-ROS programs to interact with ROS functionality. The rosbridge protocol specifies a format for sending JSON-based commands to ROS (and potentially other robot middleware systems).

During T4.1, AUTO and IDE established the architecture presented in Figure 16 to facilitate communication between RCPM and IOP:

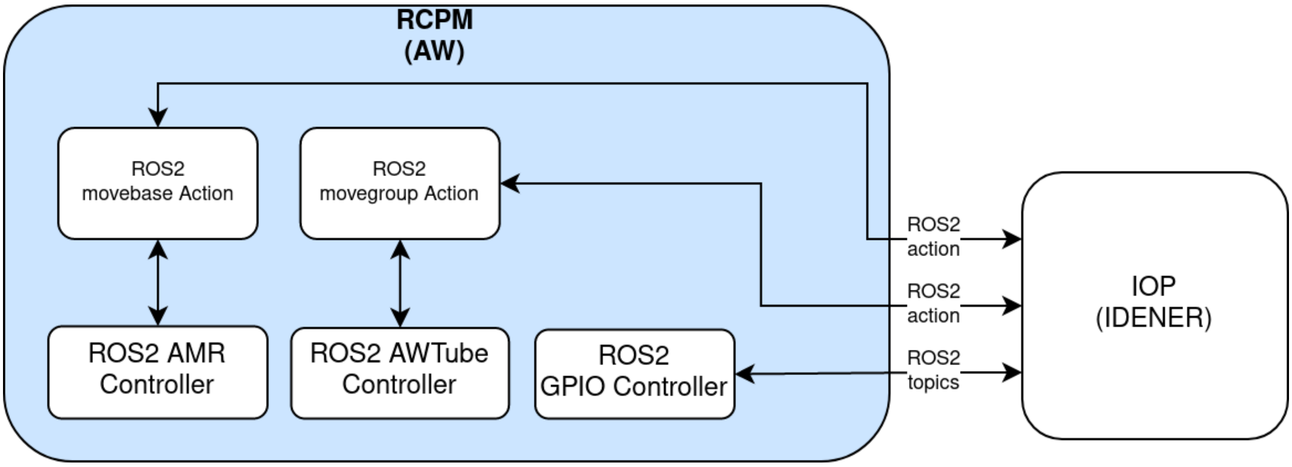


Figure 16: RCPM - IIOT communication

The software management of RCPM will be implemented using the following packages and tools:

- Movebase: offers an API that handles all the ROS2 and Action Server tasks, allowing users to focus on constructing applications that leverage the capabilities of Nav2.
- Movegroup: an easy-to-use open-source robotics manipulation platform for developing commercial applications, prototyping designs, and benchmarking algorithms.
- Pilz Industrial Motion Planner: provides a trajectory generator for planning standard robot motions such as PTP, LIN, and CIRC. AUTO selected this planner due to its deterministic nature.
- URDF (Unified Robot Description Format): a file format used to specify the geometry and structure of robots in ROS/ROS2. By collecting different URDF files, it becomes possible to assemble various robots or automation systems, or virtually recreate an entire robotic cell. "Xacro" files can be used to combine multiple URDF files, allowing the importation of robotic compositions into the ROS2 environment for advance virtual simulation of the application, even before having the hardware.
- ROS2 GPIO Controller: offers a high-level approach to receive 8 digital inputs and command 8 digital outputs directly using ROS2 topics. These can be utilized to control end-effectors.

The RCPM's physical characteristics are detailed in xacro files, which are used by MoveIt in ROS2 for avoiding physical objects during the planning phase. Additionally, the "move_group" mechanism in ROS2 offers the "planning_scene" feature, allowing the inclusion of custom obstacles or attachable objects to enhance the digital twin functionality.

The robot base can dynamically navigate around obstacles detected by lidars, and the AWCombo stack provides access to safety area settings that can be adjusted.

In terms of communication between AWCombo and IOP, AUTO and IDE have agreed that the application integrator (IDE) holds the responsibility for considering the variables dependent on the application environment, as they cannot be set beforehand. This understanding is crucial for utilizing their full potential. The safety of the RCPM's stack is managed by the safety PLC within the AWCombo. AW will provide RCPM with an architecture based on Figure 16, including a default system setup.

IDENER will have the following responsibilities:

- Integration of RCPM in their platform IOP.
- Implementing the communication between IOP and RCPM according with ROS2 Interfaces, ROS2 Client Libraries and rosbridge_suite.
- Setting the “movegroup” and “movebase” environments according to the application (eg. setup a new map for AMR, adding objects to planning scene for collision avoidance, …).
- Managing the entire decision and movements of RCPM and related end-effectors, including the data analysis from sensors measurements.
- Software management of the entire robotic cell (for MOL and ORI cases).

IDE will define modules within the IOP for each ROS2 controller and data analysis, likely utilizing the "rosbridge_suite" for interaction with ROS2. In the next steps of WP4, IDE will require information from AW regarding the data that IOP will receive from cobot sensors and the potential addition of new sensors. This information will aid IDE in defining algorithms for their modules, based on the specifications for end-user demonstration applications.

3.1.2. IOP - RCPM

The integration of the RCPM module with ROS2 involves leveraging ROS's message-passing architecture. The RCPM module utilizes rclpy, a Python library for ROS2, to publish messages on relevant topics using the ROS2 communication protocol. These topics act as channels through which data can flow between different components of the IOP. The subscribing components within the IOP can use rclpy to listen to the appropriate ROS2 topics and receive the published messages. They can then extract and process the relevant data to fulfil their respective functionalities.

To illustrate the connection between the IOP and the ROS2 node, let's consider an example. In this example, we have an RCPM module that collects performance data from a robot. The module uses rclpy to publish messages containing this data on a ROS2 topic named "/performance_data". Meanwhile, another component in the IOP, such as a monitoring module, subscribes to the "/performance_data" topic using rclpy. When the RCPM module publishes a message with performance data, the monitoring module's call back function is triggered, allowing it to extract and process the received data.

To parse and manipulate the received data, it can be employed ROS2 message parsing techniques in Python. Using rclpy, it can be accessed the specific fields within the received messages and transform them into desired formats, such as CSV or JSON. By utilizing appropriate Python libraries, like csv or json, we can save or output the extracted data in the desired format for further analysis or visualization. Additionally, libraries like rosbag can be used to record and play back the messages for offline analysis or debugging purposes, providing further flexibility in data handling.

3.1.3. Benefits of implementing ROS in the IOP

Implementing ROS2 brings several benefits to the IOP. Firstly, it provides a standardized and widely adopted framework for robot control and communication, simplifying the integration of different robotic components into the platform. By adhering to ROS conventions and using rclpy, developers can ensure compatibility and interoperability between various modules and subsystems within the IOP.

ROS's modular architecture allows the IOP to handle complex robotic systems effectively. It promotes the separation of concerns and modularity in the development process, enabling the integration of diverse hardware and software components seamlessly. This flexibility allows for scalability and adaptability in the IOP, as new robotic components can be easily incorporated by following ROS2's architecture guidelines and utilizing the available ROS2 libraries and tools.

Furthermore, ROS2's open-source nature promotes code reusability, collaboration, and community support, enhancing the development process within the IOP ecosystem. Developers can leverage existing ROS2 packages, such as sensor drivers or simulation environments, and contribute their own packages, fostering a vibrant community of robot developers. This collaborative environment facilitates knowledge sharing, troubleshooting, and continuous improvement of the IOP's capabilities.

4. Overview about safety and collaborative functionalities

In this section, an overview of the safety and collaborative functionalities is provided; these are essential for cobots. Ensuring the safe operation of industrial robots is crucial to protect both human workers and the surrounding environment. To address this, certain standards have been established to guide the design and operation of cobots. Among these standards AUTO refers mainly to ISO 10218-1:2011 and ISO/TS 15066:2016. By adhering to these standards, cobots can effectively mitigate hazards and minimize risks associated with their operation, fostering a safer and more collaborative work environment.

- ISO 10218-1:2011 specifies requirements and guidelines for the inherent safe design, protective measures and information for use of industrial robots. It describes basic hazards associated with robots and provides requirements to eliminate, or adequately reduce, the risks associated with these hazards.
- ISO/TS 15066:2016 specifies safety requirements for collaborative industrial robot systems and the work environment and supplements the requirements and guidance on collaborative industrial robot operation given in ISO 10218-1.

In the section “5.10 Collaborative operation requirements” of 10218-1, a list of the collaborative requirements for cobot is reported. In the text box are quoted the remarkable points of the section.

5.10 Collaborative operation requirements

5.10.1 General

Robots designed for collaborative operation shall provide a visual indication when the robot is in collaborative operation and shall comply with ***one or more*** *of the requirements in 5.10.2 to 5.10.5.*

5.10.2 Safety-rated monitored stop

The robot shall stop when a human is in the collaborative workspace. […]

5.10.3 Hand guiding […]

5.10.4 Speed and separation monitoring

The robot shall maintain a determined speed and separation distance from the operator. These functions may be accomplished by integral features or a combination of external inputs. Detection of the failure to maintain the determined speed or separation distance shall result in a protective stop (see 5.5.3). The speed and separation monitoring functions shall comply with 5.4.2.

The robot is simply a component in a final collaborative robot system and is not in itself sufficient for a safe collaborative operation. The collaborative operation applications are dynamic and shall be determined by the risk assessment performed during the application system design. *Information for use shall contain direction for implementing speed values and separation distances. ISO 10218-2 shall be used for designing collaborative operations. Additional information will be contained in ISO/TS 15066 (currently under preparation).*

The relative speeds of the operator and robot need to be considered when calculating the minimum safe separation distance. Minimum distance requirements can be found in ISO 13855.

5.10.5 Power and force limiting by inherent design or control

The power or force limiting function of the robot shall be in compliance with 5.4. If any parameter limit is exceeded, a protective stop shall be issued. ***The robot is only a component in a final collaborative robot system and alone is not sufficient for a safe collaborative operation.*** *The collaborative operation application shall be determined by the risk assessment performed during the application system design. Information for use shall include details for setting established parameter limits in the controlled robot. ISO 10218-2 shall be used for designing collaborative operations. Additional information will be contained in ISO/TS 15066 (currently under preparation).*

In ISO 15066 section “5.5 Collaborative operations” the following indications are reported:

5.5.1 General

Collaborative operations may include ***one or more*** *of the following methods:*

a) safety-rated monitored stop; b) hand guiding; c) speed and separation monitoring; d) power and force limiting.

As indicated in the **blue** highlighted parts, AUTO deduced that:

- Not all collaborative requirements should be satisfied to consider a robot as “collaborative”, but it shall be satisfied at least one of them.
- A collaborative robot in an absolute sense does not exist; it is its integration with sensors and ways of working that makes the application and operation collaborative.

After the overview about collaborative functionalities indicated by regulations, the collaborative behaviour shall not be expected for the single robot but for the entire applications considering that these will not be certified because the goal of the project is not to reach an industrial product.

AUTO is working to implement for AWCombo the following collaborative functionalities for the project:

- safety-rated monitored stop
- speed monitoring

To implement the collaborative functionalities FSOE technology will be integrated in AWCombo to guarantee that “fail safe” data flow through a different communication channel than the one in which “no fail safe” data are exchanged.

Other collaborative functionalities could be implemented during the project ONE4ALL, if necessary, according with the partners and the end-user applications. As described in the following chapters, some end-user applications of WP4 could not include AWCombo due to some specific requirements asked by MOL and ORI. For these reasons the safety and collaborative functionalities for RCPM (intended as the overall robotic systems for end-user demonstration applications) will be defined during the next tasks of WP4.

In any case, each RCPM (AWCombo or alternatives mechatronics/robotics solution) will be equipped by a safety system (eg. an emergency button) which will be managed by a certified commercial Safety PLC.

4.1. Human Centred Approach

As ONE4ALL innovations delve into the realm of robots and automation, a human-centred approach is embraced, placing the well-being and safety of humans at the forefront. The collaborative robots within RCPM and connected with the IOP are designed with ergonomic factors in mind, incorporating intuitive interfaces and user-friendly features. ONE4ALL prioritise the comfort and ease of use for human operators, we can foster enhanced human-robot interaction and cooperation. By seamlessly integrating into the workflow, these cobots assist humans in performing monotonous and repetitive work, allowing them to focus on more complex and value-added activities. Rather than replacing humans, the cobots are intended to work alongside them, augmenting their abilities and fostering a symbiotic relationship between humans and machines. Asking workers for (training) requirements for RCPM and IOP implementation in task 1.1 might raise further criteria for acceptance and well-being among the workers. These emerging criteria will be addressed as additional requirements to the technological solutions. To enable the smoothest possible integration of possible employee requirements into the technological solution, a continuous and mutual coordination between the end-users and the developer of the technological solution is necessary. The close cooperation between AUTO, INO and TUDO in T1.1 ensures this. The definition of a use case in the application companies is the basis for this.

Ethics are a crucial consideration in the development and deployment of the RCPM. ONE4ALL consortium understand the importance of transparency, privacy, and data security. The RCPM digital infrastructure adhere to legal and regulatory frameworks, ensuring that their behaviour and decision-making processes are explainable and accountable. By upholding security & ethical standards, such as:

- ✓ Fulfilment of data management guidelines and requirements, such as the General Data Protection Regulation (GDPR). Those will be detailed in the data management plan (DMP) deliverable 7.7.

- ✓ Worker’s safety and job quality improvement as priority. Consider mental and physical integrity of workers, e.g. due to the implementation of the cobots, which must not harm workers. In upcoming deliverables it will be described in reports how workers are protected and safety regulations and standards will be identified in T4.2.
- ✓ Environmental protection. The development of the RCPM will align and fulfil the specifications outlined in WP1 in regard to the sustainability and environmental targets.
- ✓ Improve workers understanding of the RCPM capabilities and opportunities in regard to their jobs. Moreover, ease the adaptation of the workers to those novel technologies. Aligning with WP1 activities and gender & ethics requirements settled in T7.5 By TUDO.

In conclusion, the aim is to cultivate trust, acceptance, and responsible use of the RCPM within the IOP ecosystem.

The efforts in integrating collaboration and a human-centred approach within the RCPM and into the IOP mark an advancement from Industry 4.0 to 5.0. The scope of I5.0 is that humans and robots work together as partners, leveraging each other's strengths to achieve higher productivity, innovation, and sustainability via complementarity [1] of humans and cobots. In this paradigm, the cobots play a vital role, taking on more tasks and actively learning from their human counterparts. This transition represents a shift towards a more interconnected, human-centric, and socially responsible approach to robotics and automation.

As ONE4ALL activities move forward, there are important next steps to consider. TUDO and INO are committed to providing education and training programmes to equip individuals with the skills needed to effectively collaborate with the cobots. Finally, emphasise the importance of interdisciplinary collaborations and open dialogues to promote responsible and sustainable deployment of collaborative cobots within the IOP.

5. Madama Oliva demonstration site inspection

Madama Oliva (MOL) demonstration site facilities has been visited by AUTO, CRIT and INO on March 7th, 2023. IDE joined the technical visit virtually. During the meeting, partners visited the MOL's production site and focused their attention on the possible end-user applications for RCPM, described in the following subchapters. Additionally, several virtual meetings have been held in order to properly define MOL demonstration activities for ONE4ALL, and in regard to T4.1 and this deliverable, the requirements of the RCPM. In Figure 17 is presented the workflow of the production process in MOL facility.

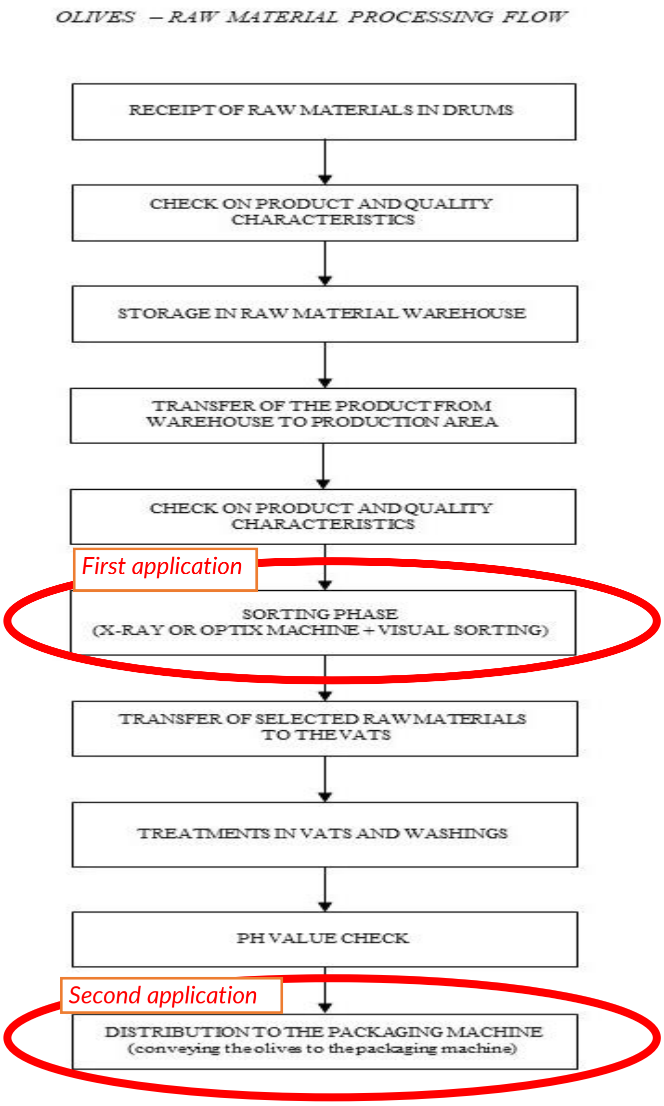


Figure 17: Madama Oliva products processing flow

5.1. Activities inspection summary

5.1.1. Sorting of olives

The sorting phase consist of the selection of olives based on defect and colour characteristics on a sorting belt. This phase of the process involves the identification and removal of olives that do not conform to the quality standard while the flow of olives runs on a sorting belt. The belt is equipped with several lanes where the discarded olives must be divided and then classified by type and severity of defects, to be used in other production processes or definitively eliminated. It is important to remark that the production line is in a wet and salty environment. This kind of environment is very challenging for a mobile and collaborative robotic solution.

The shorting phase is divided into two stages. For the first stage of sorting, MOL currently uses an automatized method based on a conveyor belt for sorting olives according to their colour. The method integrates a vision system (Multi Scan machine) which identify the defected olives discards them. However, the system is not very accurate. It only discards the olives based on their colour and just some type of defects, summing up the high throughput of olives, most of the defected olives are not discarded by the system. The second stage of the sorting task is successively performed by human operators who identify aesthetic defects of olives by visual checking.

As starting point for T4.2 and T2.2 there have already been preliminarily identified the usual defects presented by different kind of olives. Those are presented in Figure 18. T2.2 will deep in the products quality standards and how those must be fulfilled in order to enhance the overall quality of the end product. Therefore, further details in this regard will be presented in D2.2. In addition, the dataset provided by MOL detailing the defects identification of their olives will help the selection of monitoring system within T4.2 and AI-based algorithms for their detection.

Figure 18: Olives' usual defects per different types of olives

5.1.2. End of line activities

The end of line (EOL) activities play a crucial role in the final stages of product handling and preparation. These activities primarily involve the careful handling, quality checks, and efficient palletization of various packages that contain a wide range of products. Among the most common packages encountered in EOL activities are trays, pouches, jars, and pails, each varying in size and shape (as shown in Figure 19). The typology and quality requirements of the products is traced through a SKU code. Every code is associated with a different product and each one requires different checks, hence different activities. So far the code is registered manually and is not yet implemented a digital system to handle them. Nevertheless, MOL plan to digitalise their facilities in this sense and implement an ERM system. Additionally, as part of ONE4ALL activities, in T4.2. there will be ensured that the codes associated to the products can be identified (i.e., through a visual system attached to the RCPM) and stored in the IOP to identify the quality checks and activities associated and transform them into orders for the RCPM.

Figure 19: Example of EOL products

Currently, those activities are performed manually by human operators. By implementing the RCPM to collaborate and support the human operators the EOL activities can be transformed into efficient and streamlined processes. In this sense, the EOL activities provide an ideal testing ground and practical applications for the capabilities of the RCPM. With their inherent variability and diverse product types, these tasks pose unique challenges, as well as the synchronic work with the human operators towards an I5.0 transformation.

5.2. *ONE4ALL applications and solutions*

5.2.1. Sorting of olives

As already mentioned, the sorting of olives phase presents an unexpected environment. Given the hazardous environment (wet and salty) for a collaborative and mobile robot, it has been decided that the AWCombo proposed as core for the RCPM is not a suitable solution. Moreover, would neither fulfil the activity requirements in terms of efficiency and accuracy sorting the olives, given the high throughput of olives. It is necessary to use a robotic or mechatronics solution which can be reliable in difficult environmental conditions and which can work with the required high speed rates. For these reasons, according to the specific MOL's request to implement the "sorting of olives", AUTO and the other involved partners are evaluating two possible solutions:

5.2.1.1. Solution 1

The proposed robotic solution is a delta robot especially made for food applications and compatible with the environmental characteristics of the site and task requirements. Delta robot is the fastest parallel robot type, it works on 4 axes, it is made of stainless steel with a degree of protection IP67 to be compatible with the MOL's working condition. Due to the very high-speed performances of this robot, it is not collaborative. Nevertheless, it will be reconfigurable. There will be required an improved vision system to accurately identify the type of olives, the defected olives and through the IOP orchestrate the system to select the suitable tools to pick the type of olives. The vision system provided by INO should execute two main tasks:

- Perform the quality check on the olives to the detect the defected ones. IDE will support on the development of an AI-based algorithm (i.e. based on DNNs such as YOLO – usually implemented for real-time objects detection) to detect the defected olives. This could serve a starting point for the defected olives detection. Similar approaches can be implemented in other activities performed by the cobots in regard to objects detection. Those algorithms can be implemented in the IOP as an "general-purpose objects detection module".
- Tracking the position of the defected olives to allow the robot to discard them. The vision system will report the X-axis locations (position across conveyor belt), Y-axis position relative to an agreed fixed point, and high-precision time of capture information. This will allow the position of the "bad" olive to be calculated as a function of time & conveyor speed as it moves along the belt towards the delta robot. This should be more efficient and less costly than attempting to track bad olives all the way along the conveyor until they reach to robot, as well as negating possible data lag in transfer of real-time position data via the IOP.

As parallel objectives to achieve the best performances, it is essential to reduce the olives detection time, communication time between the systems involved, trajectories calculation and robot execution. IDE will manage all the data transfer in real-time as well as the services execution through the IOP. In other words, the IOP will be the intermediary. The preliminary proposal is to perform the sorting of olives after the colour quality check done by the "Multi Scan machine"; replacing the current conveyor belt with a different conveyor which allows to rotate the olives and keep them in separated tracks, like the conveyor in Figure 20, helping the sorting of olives with the robotic solution.

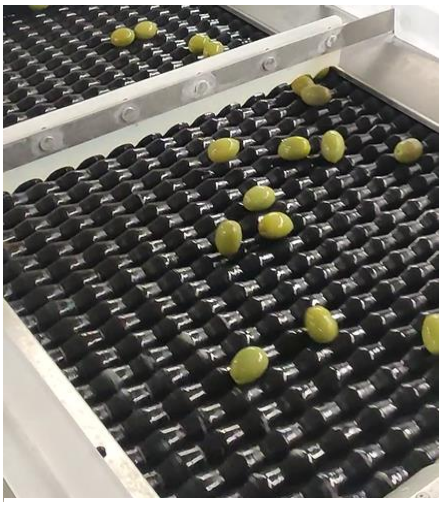


Figure 20: Conveyer belt proposed

5.2.1.2. Solution 2

A second solution can be implemented modifying the existing conveyor belt adding to it a system to check also the aesthetic defects of olives and automatizing the discarding of defected olives (eg. using compressed air to blow the olives). This solution does not include a RCPM or a robot, but an automation system combined with the vision system developed by INO and IDE.

5.2.2. End of line activities

In conclusion, for those activities the RCPM will handle and check the quality of multiple types of products which come in different sizes. This will require the auto-reconfiguration of the RCPM to adapt to each product. The types of packages with their related format and sizes, the estimated throughput in a year and other features, has already been shared by MOL. In the next steps of WP4 it will be necessary to identify the specific SKU codes of the products and fully characterize the checks and activities required by each product. For each SKU, MOL will provide:

- Physical dimensions of packages and weight.
- The list of quality checks to be executed.
- EOL specifications and activities to be executed (e.g., labelling, boxing the products, palletizing).

After the definition of the involved SKUs, the solutions for end-effectors, sensors and vision system to be used will be defined and developed by the involved partners in T4.2. In parallel, in T4.4 there will be developed the cobot with different grips and tools to handle and process the products on the end of line. Additionally, those tools will be interchangeable enabling the auto-reconfiguration of the RCPM. Lastly, in T4.3 there will be identified and ensured the fulfillment of any standards related to the activity and especially the safety of the workers. Meanwhile, in T1.1. INO and TUDO will lead the training activities of the workers to ensure the human-centered approach and the path towards I5.0.

6. Orifarm demonstration site inspection

Orifarm facilities were visited at the start of the project in order to have a clear overview of the whole production process and the ONE4ALL possibilities regarding RCPMs. In this section, an overview of the facilities is going to be introduced as well as the challenges related to addressing the diverse activities. Active communication has taken place among the involver partners to come up with the final applications that are collected in the subsection 6.3.

Figure 21: ORIFARM facilities

As appreciated in Figure 21, ORI facilities are divided into different buildings, each one devoted to certain activities. The same way, their process is divided into diverse task, the goods are received, checked in terms of quality and repacked, registered into the internal system (ERP) and afterwards stored. These new “products” are then prepared to be included in the orders from the customers.

6.1. RCPMs possibilities

Considering the diverse scope and extensive nature of the ORI production process, there exist numerous potential applications that can be effectively addressed using RCPMs. Throughout the entire duration of Task 4.1, careful analysis has been conducted to identify the most promising and strategically advantageous opportunities aligning with the objectives of the ONE4ALL project. In this sense, the diverse applications discussed can be outlined:

1. Application 1 – Pick & Place of Orifarm’s standard boxes from a starting point to the working cells.
   In this application AWCombo acts as RCPM implementing the following tasks:
   - Pick&Place with Robot arm with vision system for detection, bar code and calibration.
   - Travelling to each working cells to bring there the boxes.

Figure 22: Proposed Application 1

2. Application 2 – Bin-picking of pharma boxes after manual reworking with quality checks.

In this application AWCombo acts as RCPM implementing the following tasks:

- Pick&Place of pharma boxes from a buffer (like a rotary table) or from a conveyor with vision system for bin-picking and then placing them in a standard box or production basket.
- Pharma box weight check for quality control with a force sensor on the robot gripper.
- Barcode or other visual controls for quality checks using a vision system.
  For INO, partners should carefully define required & desired quality attributes to measure with ORI. Tasks such as barcode reading will be low risk but assessing potential damage to boxes etc. will carry higher technical risk. Best to structure in such a way as to ensure that even if some higher risk objectives can't be achieved the overall key functionality can still be delivered.

Figure 23: Proposed Solution 2

- Travelling with AWCombo for moving Orifarm's standard boxes to the end of production sorting point.

3. Application 3 – Interaction with ERP and pharma boxes pick&place for customized orders. In this application AWCombo acts as RCPM implementing the following tasks:
   - It receives the order from the ERP.
   - It travels and picks pharma boxes from the warehouse using vision system for bar code reading and pharma boxes detection.
   - It travels to operators workstation and place the boxes.
   - After operators control & pack activities, the robot picks the final shipping box and carry it to the shipping area.
   - It updates the ERP about the completion of the order.

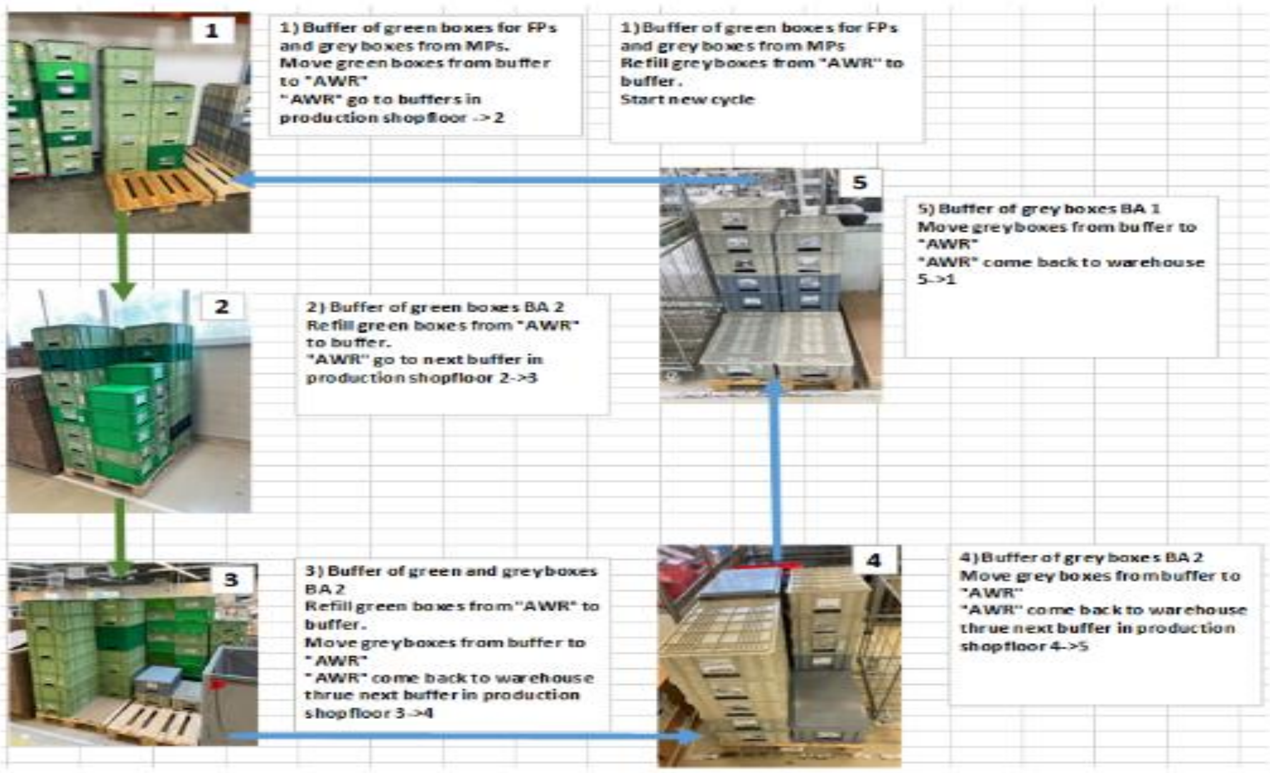
INO suggested utilizing force and/or ultrasonic distance sensors on gripper to ensure boxes are not crushed while engaging suction cups. May require hybrid IIoT approach with parallel IIoT and direct integration with ROS to provide time-critical during movements.

Figure 24: Proposed Application 3

Through additional meetings and discussion, it was settled with ORI that the biggest application opportunity for ONE4ALL technologies is on the intralogistics production workshop (automated goods transport to processing cabins). For AUTO these requirements can be handled using AWCombo and an AMR/AGV. AWCombo can be used to pick and place objects and to palletize them on pallets which will be transported in different points of the ORI’s facilities by an AGV/AMR. These new ideas are reported in applications 4 and 5:

4. Application 4 – Moving plastic boxes for FPs (green) to shipping floor buffers and plastic boxes from MPs (grey) to warehouse.

Figure 25: Application 4 intralogistics layout



1) Buffer of green boxes for FPs
and grey boxes from MPs.
Move green boxes from buffer
to "AWR"
"AWR" go to buffers in
production shopfloor -> 2

1) Buffer of green boxes for FPs
and grey boxes from MPs
Refill greyboxes from "AWR" to
buffer.
Start new cycle

5) Buffer of grey boxes BA 1
Move greyboxes from buffer to
"AWR"
"AWR" come back to warehouse
5->1

2) Buffer of green boxes BA 2
Refill green boxes from "AWR"
to buffer.
"AWR" go to next buffer in
production shopfloor 2->3

3) Buffer of green and greyboxes
BA 2
Refill green boxes from "AWR" to
buffer.
Move greyboxes from buffer to
"AWR"
"AWR" come back to warehouse
thrue next buffer in production
shopfloor 3->4

4) Buffer of grey boxes BA 2
Move grey boxes from buffer to
"AWR"
"AWR" come back to warehouse
thrue next buffer in production
shopfloor 4->5

Figure 26: Application 4 intralogistics flow

Application 5 – Assembling and rearranging the boxes.

Figure 27: Application 5 proposed by ORI

6.2. *Challenges*

To ensure accurate identification of the application(s) that best align with the objectives of ONE4ALL, a comprehensive analysis of the unique challenges associated with each Application proposed has been undertaken. This rigorous evaluation process has involved extensive discussions among the use cases and partners involved in the development of the technological solutions. As a result, certain aspects have been identified that rendered some applications unsuitable and therefore excluded from consideration due to their inherent limitations.

- Application 1 was discarded due to high variability of dimensions, sizes, types of packaging in Inbound process ORI cannot provide full set of dimensions from database, or a standardized way to identify the products typology given their variability.
- About Application 2, in case of cobot application ORI see different speed of handling compared to manual operation. They cannot provide a complete database of dimensions of FP boxes to teach robotic grab.
- Application 3 was the most promising one. However, had also to be discarded due to the fact that products throughput will be reduced a 90% because the activity is intended to be moved to a new facility in Germany by the Q1 2024. Therefore, whenever the solution will be developed, the throughput of products and the activities will no more be available for testing in good conditions the potential of RPCMs.
- About Application 5 AUTO, INO and IDE consider it not feasible or appropriate for the ONE4ALL project's purposes. Application 5 would require an automatised solution, neither collaborative nor reconfigurable, which escapes ONE4ALL innovation purposes.

Furthermore, constraints regarding products variability were considered in order to establish manageable parameters within the ONE4ALL applications. As per the request of AUTO, IDE, and INO; ORI determined a finite number of products to be handled. This decision was necessary due to the inherent limitations of the reconfigurability of a RCPM. Therefore, a specific set of objects was defined to be managed during the end-user demonstration applications.

Additionally, the challenges at the organizational level must be also considered while deciding and defining the final application. Firstly, there is a need to ensure proper alignment and coordination among various departments involved, such as production, engineering, and IT (ERP system). The implementation of such a solution requires close collaboration and effective communication between these departments to address any potential conflicts and ensure smooth integration. There may be required some changes in existing processes workflows and roles. In this sense, employees need to be trained and prepared for working alongside the robotic system and leveraging the IIoT platform, this will be certainly addressed by the upskilling programs and human-centricity approach (see section 7.1).

By carefully considering all the aspects discussed in this section, ORIFARM can effectively leverage the advantages offered by the robotic solution and the IOP. This approach allows for the optimization of benefits while simultaneously minimizing potential disruptions and ensuring a smooth and successful integration process.

6.3. Orifarm applications

Noting ORI's considerations of previous proposals made by partners, the end-user demonstration application which is potentially the most feasible to be implemented in ORI is the “Application 4” previously presented: Moving plastic boxes for FPs (green) to shipping floor buffers and plastic boxes from MPs (grey) to warehouse.

“Application 4” consists of fill in boxes with the variable products handled within ORI facilities and picking and placing those boxes (two different types) from a buffer to a pallet and vice versa in different points of the ORI’s facilities (see Figure 25). From AUTO’s side, RCPM could be considered as a combination of AWCombo and another mobile robot. AWCombo could be used for executing “pick & place” and “palletizing” tasks while the other mobile robot could be used to transport pallet with boxes in different points of ORI’s site.

In the forthcoming months, further refinement of the application's specifications will be undertaken, including the selection of appropriate end-effectors, cameras, and sensors for integration with the collaborative cobot, as part of T4.2 and T4.5. The final configuration of the robot, aligning with the flexibility principles of the RPCM system, will be documented in upcoming deliverables within WP4. These deliverables will provide comprehensive details regarding the optimal robot solution for successfully executing the designated task.

Figure 28: Boxes handled in application 4 in ORI use case

7. Conclusions – RCPM development plan (next steps)

The development plan is shown in Table 4, disclosing the tasks starting in M6 in subtasks and with a preliminary time frame.

*Table 4: RCPM development plan - WP4 planning (*preliminary starting and ending dates)*

Task	Description	Leader	Start	End
T4.1	**RCPM specifications, requirements and workplan**	**AUTO**	**M1**	**M5**
T4.1.1	Site inspections for user cases	AUTO	M1	M3
T4.1.2	Feasibility of user cases activities with AWCombo	AUTO	M1	M5
T4.1.3	Definition of alternative solutions for RCPM where AWCombo is not compatible	AUTO	M1	M5
T4.1.4	Define the final specifications for end-user demonstration applications	AUTO	M1	M5
T4.2	**IIOT devices for real-time monitorisation**	**INO**	**M6**	**M30**
T4.2.1	Monitoring devices selections	INO	M6	M8
T4.2.2	Development & acquirement of monitoring devices	INO	M8	M12
T4.2.3	Installation of the monitoring devices and testing	INO	M10	M18
T4.2.3.1	Connection with the IOP	IDE	M10	M18
T4.2.3.2	Cobots integration	AUTO	M10	M18
T4.2.4	IIOT real-time monitoring system deployment and final version	INO	M18	M30
T4.3	**Standardisation activities**	**CRIT**	**M6**	**M48**
T4.3.1	Identify standards related and to be fulfilled by ONE4ALL technologies	CRIT	M6	M18
T4.3.2	Contribute to existing standards	CRIT	M6	M48
T4.3.3	Standards fulfilment guidelines & ensure their fulfilment	CRIT	M18	M48
T4.4	**Cobots development and integration with the digital tools**	**AUTO**	**M6**	**M30**
T4.4.1	Refine and detail the specifications of the demonstration activities in regard to RCPM design and development – Products to be handled and their characterisation. Align with T2.2.	AUTO	M6	M7
T4.4.2	AWCombo hardware design and development	AUTO	M6	M12
T4.4.3	AWCombo software design and development	AUTO	M6	M15
T4.4.4	AWCombo safety and collaborative functions design and development	AUTO	M6	M15
T4.4.5	Integration of vision, sensor and end-effector systems developed with partners for RCPM solutions	AUTO	M6	M15
T4.4.6	Production of the first AWCombo unit for ONE4ALL	AUTO	M9	M15
T4.4.7	AUTO's internal testing of the first AWCombo unit for ONE4ALL	AUTO	M15	M18
T4.4.8	Definition, design and development of alternative RCPM solutions instead of AWCombo	AUTO	M6	M15
T4.4.9	AUTO's internal testing of the alternative solutions	AUTO	M15	M18
T4.4.10	Delivery of first unit of RCPM to SDU	AUTO	M18	M18
T4.4.11	Further tests, designs and developments of RCPM solutions	AUTO	M18	M30
T4.5	**Testing and validation of the RCPM and the digital tools**	**SDU**	**M19**	**M30**

This is a first version of the Development Plan serves as a detailed preliminary workplan for upcoming tasks of WP4 and in regard to the RCPM development. The workplan may be modified during the execution of WP4 according to the advancements and challenges.

Currently the main focus will be on settling and characterising the types of products to be managed by RCPM, also aligning with T2.2 focusing on defining the products quality checks requirements:

- A finite number of types of olives to be sorted for MOL.
- A finite number of types of jars, pails and trays to be managed for MOL.
- A finite number of boxes to be managed for ORI.

References and Resources

[1] Nöhring, Fabian; Wöstmann, René; Wienzek, Tobias; Deuse, Jochen (2019): Socio-Technical Capability Assessment to Support Implementation of Cyber-Physical Production Systems in Line with People and Organization. In: Nunes, Isabel (eds): Advances in Human Factors and Systems Interaction. AHFE 2018. Advances in Intelligent Systems and Computing, vol. 781