ACROBA

connect & produce through agile production

D2.2 “Robot Modules Architecture”

WP2

Lead Beneficiary DEUSTO

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Approval Status

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History of Changes

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1.0	2021.12.22	Revised version with corrections	Alberto Tellaeche

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Executive Summary

This deliverable is the second document related to task 2.1, and describes the formal application of the software architecture developed in WP1 to the industrial use cases proposed by the project partners. The hardware needs and skills defined for each use case will be specified after their in-depth study, in order to finally define the task planner associated to each of the processes that will orchestrate their global execution.

The detailed definition of each use case can be found in the corresponding deliverables of WP 4 and 5. These documents are:

- D4.1: "Medical Device Pilot Line Specifications"
- D4.2: "Plastic Pilot Line Specifications"
- D5.1: "Electronic Components Pilot Line Specifications"
- D5.2: "Electric Motor Pilot Line Specifications"

1 Introduction

During the first year of implementation of the ACROBA project, most of the project's efforts have been directed towards the creation of a generic software architecture that could support the development of advanced robotics applications, thus facilitating the application of the latest trends in artificial intelligence, collaborative robotics, sensor technology and flexible manufacturing to previously existing industrial facilities, with the ultimate goal of drastically increasing their efficiency and competitiveness. The first stable version of this architecture available for use will be published on M12 of the project, ending this way the activities planned in WP1 of the project.

Of all the modules that make up the SW architecture developed, the Task Planner is of particular relevance, responsible for managing the operating logic of the entire process that makes up a given use case, based on skills. The task planner is being developed in T2.3 corresponding to WP2.

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In parallel to the development of the SW architecture in WP1, the use cases have been studied in depth in WP4 and WP5.

WP4 covers cases where robots operate autonomously, without direct collaboration with humans. WP5, on the other hand, specifies the needs of use cases where collaborative robotics is used.

This deliverable is the result of the execution of T2.1 between M6 and M12.

In the first 6 months of this task the necessary requirements for the generic test use case to be developed in WP3 were specified, while in months 6 to 12 the actual use cases present in the project have been formally specified.

This document collects this formal specification of the latter, in order to facilitate their direct implementation in the architecture proposed in WP1.

The formal specification of these use cases has been done using the software tool “Papyrus for Robotics”. This tool, based on the open platform Eclipse, was created in the European project RobMoSys, and provides a user-friendly environment to create behaviour trees and to define needed skills for the different processes. These Papyrus for Robotics projects are available if needed.

2 ACROBA Architecture

2.1 Current status of the architecture

In deliverable D1.1, a formal study was carried out at the beginning of the project to identify the specific needs of each of the use cases. Likewise, the execution flow of the different processes of the use cases was studied prior to the start of the project, identifying the specific points of these processes in which the ACROBA architecture and the modules developed in the future would help to improve them.

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With the previously explained information available, an architecture using microservices was applied, based on the DDD (Domain Driven Design) paradigm of software architecture.

Following this architecture, and attending to the specific needs identified that the platform must support, an architecture based on modules and skills executed from a logic implemented in a task planner has been designed. Detailed information on the structure of the architecture and its high- and low-level communications can be found in deliverable D1.2.

A first functional version of the ACROBA architecture has been created in task T1.3.

As a result of this task, a GitHub repository is available in the cloud, with all the software needed to deploy the architecture quickly on a local PC.

The SW repository also contains a readme file with precise instructions for deploying the architecture, running demos and developing new applications.

The repository link is the following: https://github.com/ACROBA-Project/ACROBA-Architecture

2.2 Updated schema of the ACROBA Architecture

The following figure shows in detail the current software structure that has been created for the ACROBA architecture.

It shows the different skills, the generic modules available for use in the use cases, the two levels of communication, both at plant and office level, and finally the task planner, which is responsible for the execution logic of the use cases that are programmed.

The black arrows indicate, in a simplified way, the flow of information that occurs between the different constituent elements of the platform.

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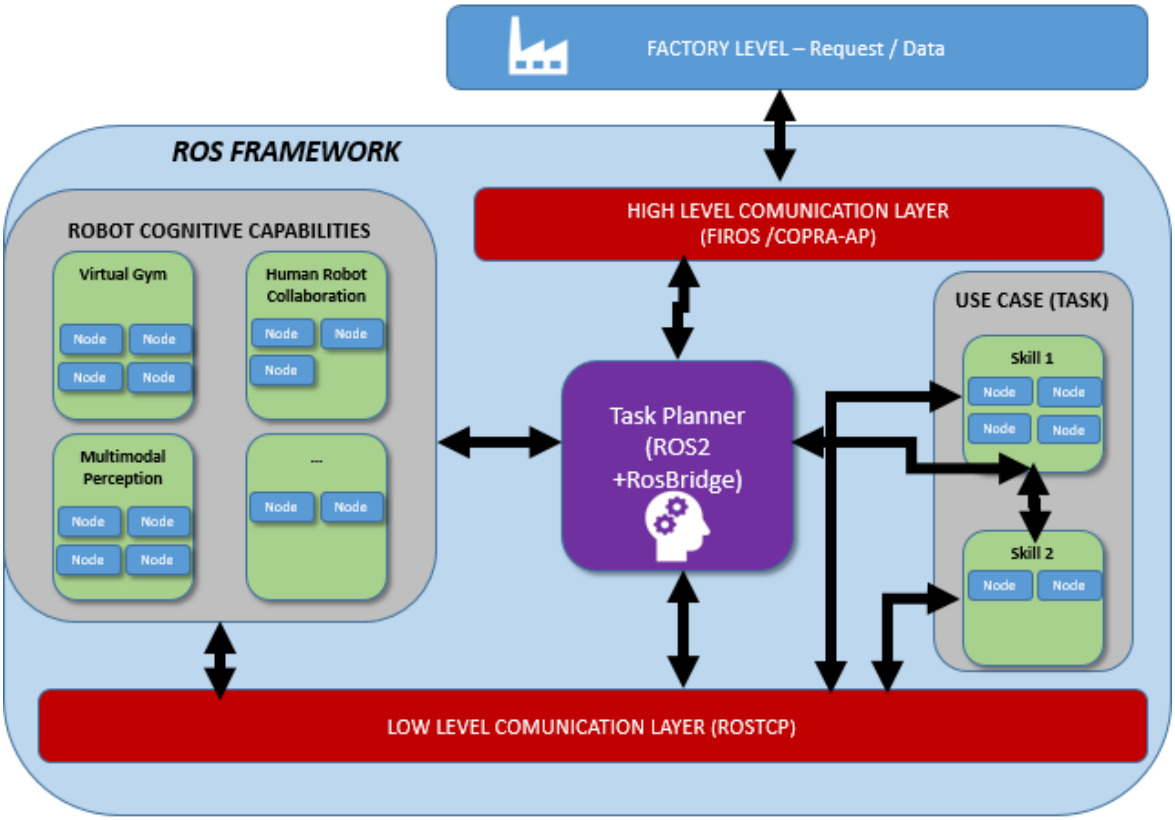
Figure 1 – General schema of the ACROBA architecture



When the system starts, a global launcher will start in parallel the task planner, the developed skills and the specific modules used in the use case to be executed. Once all the necessary software elements are initialized, the task planner will execute the different necessary operations in the logical sequence that has been established for the use case.

2.3 Related hardware

ACROBA architecture is based on ROS framework [1] for sensor and robot drivers, as well as to manage factory level real time communications.

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Taking this aspect into account, al the sensors and hardware needed in the different use cases of the project must comply with this requirement. To do this, several points must be considered when selecting a specific piece of hardware to be integrated into the platform. These are:

- Existence of a direct ROS driver for the hardware selected. This point is the preferable option, leveraging the work needed to integrate the sensor or element directly in the platform.
- If there is not a built ROS driver for the hardware element, it is needed the availability of an API (application programming interface) for the Linux OS. By using this API, it is possible to create a ROS driver for the hardware device.
- The hardware device gives a detailed specification of the communication protocol implemented to transfer the information. In this case, by using generic libraries of the Linux OS, a bidirectional communication can be implemented, accessing the sensor data directly by using the defined protocol.

In any case, it is mandatory that the sensor can be read from a Linux machine so that it can be integrated in the ACROBA platform. In the next sections of this document, there is a tentative list of needed hardware for each use case. The data types expected to be used for each of these hardware elements are also specified, taking into account the standard ROS messages that it would be logical to use for transmission at the factory level.

2.4 ACROBA modules

A number of generic modules are provided within the ACROBA architecture. These modules are designed so that, by means of a previous configuration, they can be used in the different skills that will be created for the different use cases in the project.

A simple example of this way of working could be the use of the Deep Reinforcement Learning (DRL) module applied to the specific problems previously selected from the different use cases, to solve certain operations using this technology.

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Due to their cross functional nature to be used in different tasks, a flexible configuration system is needed in each of these modules. Also, all generic modules created on the ACROBA platform, after being configured, will communicate using the low-level protocol provided by the underlying standard used, ROS. For this purpose, the modules must clearly establish their communication interface and the types of data used for it.

The modules established to be included in the architecture are presented in the following sections.

2.4.1 Robot Control and Perception Module

This module defines the perception and control algorithms for detecting and manipulating a product. These algorithms are wrapped into skills. Detailed of the skills for each use case are given below in Section 3.

Figure 2 – **Example of skills and primitives required for a bin-picking task.**

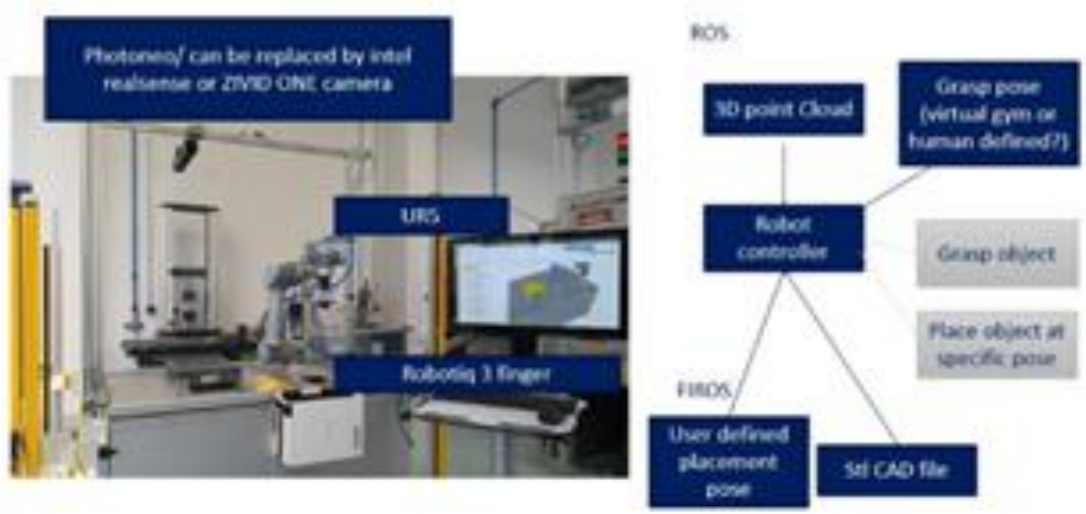

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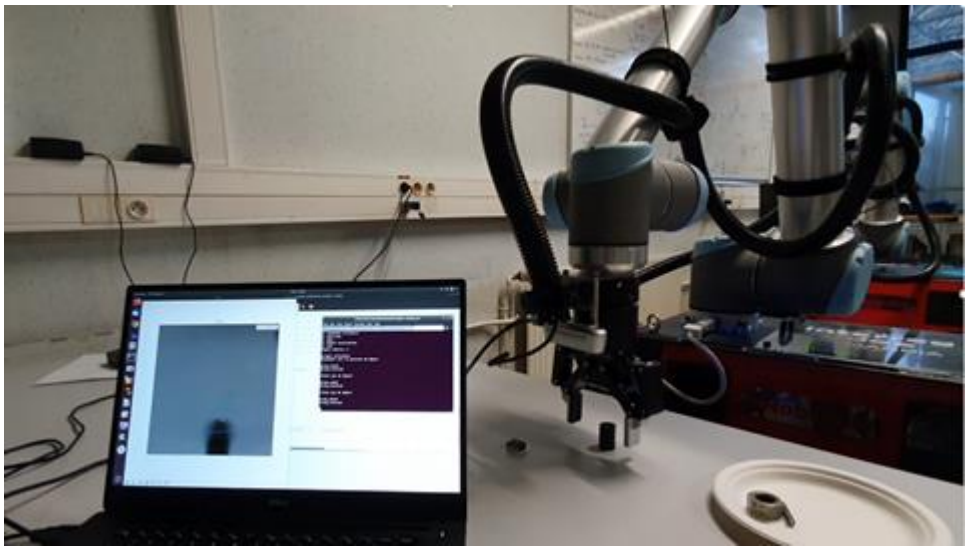
Figure 3 – Experimental Validation of Grasp Synthesis



The formalization of the different algorithms is performed as skills nodes under ROS1 framework. It should be denoted that further studies about ROS2 will be conducted in the next months. These skills nodes are wrapper over one or several primitives that give access to atomic functionalities**.**

While the sensors primitives (drivers) are mostly hardware-agnostic and can directly be used for defining the perception skills, this is not the case for robot drivers. Indeed, the control primitives for UR robots are different from the control primitives for ABB robots. Since different robots are used in the use-cases, and to comply with the purpose of ACROBA project, for future developments robot-agnostic solutions are needed. In particular, solutions based on ROS Industrial framework will be implemented.

2.4.2 Task planner

The task planner is a particular module within the architecture in charge of controlling the logical execution of the different skills that make up a given use case.

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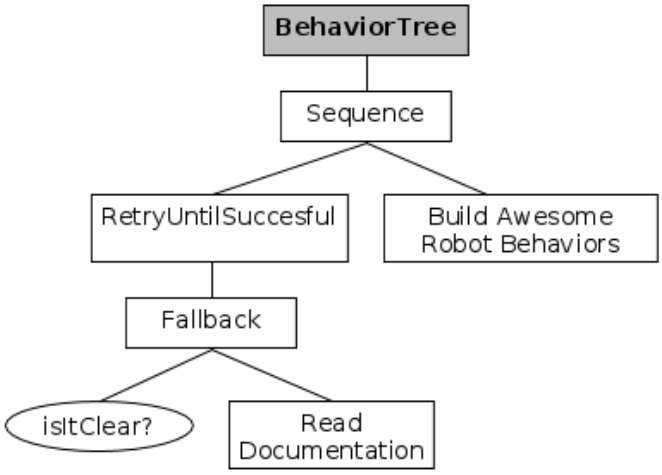
For the formal definition of the execution sequence of the different skills, the task planner uses behaviour trees (BT).

BTs are a more flexible alternative to traditional state machines, and allow the definition of all the types of activities typically used in robotic applications: sequences, decisions, etc.

Figure 4 - **Example of a behavior tree**



For more information on the basics of BTs (architecture, key elements, operating logic, etc.), please refer to the following references [2].

The ACROBA architecture uses several specific software tools for the implementation of the task planner. They are the following:

- ROS2 core: ROS 2 execution core, necessary for the processing tools used for BT creation.
- Behavior tree library (BehaviorTree.CPP): a C++ library to create a process BT. It is used for programming the core of the Task Planner. [3]
- Groot: A graphical editor, based on the previous library, to create a manage BT. [4]

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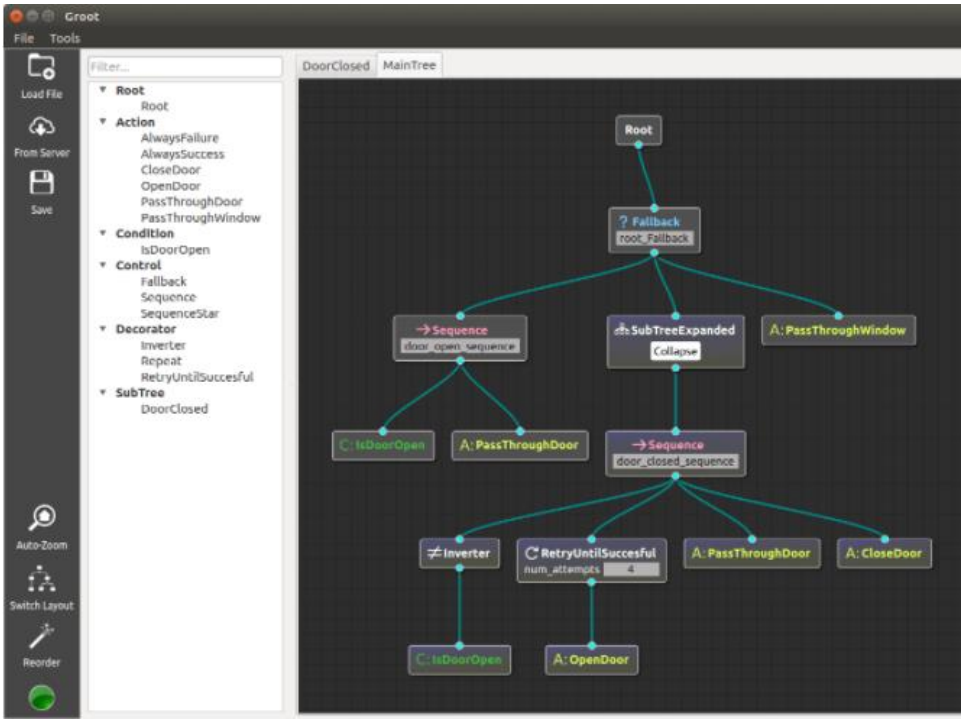
This last editor might be replaced or extended at later stage of development. In further development of the task planner, the following features will be developed:

- Visualization and edition of the Task with a GUI, manual or automatic generation of corresponding Behavior Tree
- Possible optimization of the sequence based on a problem-solving algorithm (run by Plansys2)
- Online re-planning (as sub-behavior trees) for an adaptive robot behavior to its environment (for example human perturbation in the process)

Figure 5 - The Groot environment



This document gathers all the behavior trees created for each use case, thus specifying the execution of the different skills in each of them. By defining the BTs and skills of a given use case, its execution and implementation is fully defined in a formal way.

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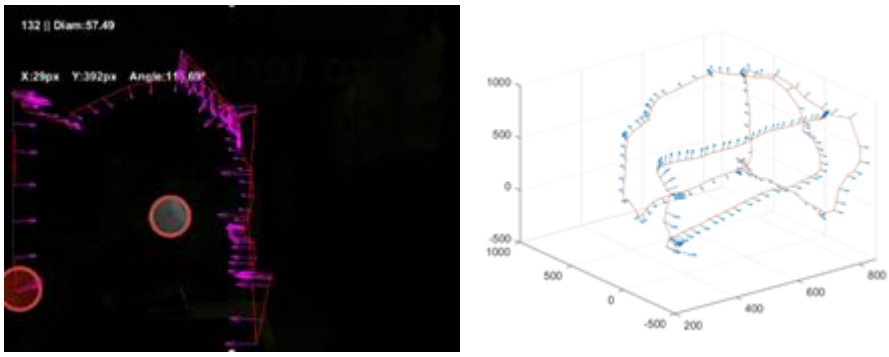
As with the skill definitions, at this stage of the project the BT specifying the task planner have been created at a theoretical level, and they will possibly require further refinement in real setups.

2.4.3 Dummy Tool Module

After conducting a feasibility study of the tool accuracy reading, a series of prototypes have been made, and their monitoring has been carried out by means of vision cameras. In this way, it has been evolving by making modifications in light, colour, shape or size until reaching the current prototype.

Figure 6 - Dummy Toll 3D tracking results



2.4.4 Cognitive Human-Robot Collaboration Module

Human-robot collaboration module requires to extract several features related to the human perception during the task execution. For safe interaction, it is necessary to detect the state of the human operators in real-time. Among others, tracking and detecting human activity are some essential features to develop

Human-robot collaboration regroups several configurations, and, in this module, we focus on activities between humans and objects, that induce actions and gestures. Activities regrouping two or several humans are currently out of the scope but could be considered depending on additional use cases scenarios.

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From this context, a list of modalities that could be used for determining human activity or state have been determined as follows:

- Video stream: Human tracking or activity recognition generally requires exploiting spatio-temporality of an action. Single image snapshots may not be sufficient to disambiguate the activity being performed.
- Sound: Although sound is seldom used compared to visual perception, in industrial context, specific machine sounds could help determine the activity performed by the human operator. Several research topics focus on the interpretation of audio-visual features, as stressed by the recently released dataset VGGsound.
- Wearable devices: A fiber-based human wearable device, developed in WP3 would be used to track human state. As this device is not available yet, an alternative solution, OpenPose (based only on video stream), have been investigated. OpenPose is a real-time multi-person detection based on a monocular camera.
- Inertial sensors: Nowadays IMU data could be gathered from daily-life objects such as smartphones. Being less invasive than wearable devices, and not limited spatially as cameras (occlusion, field of view), this modality provides a flexible way to detect human activity. Nonetheless, the accuracy of such a system may be lower than more conventional modalities.

2.4.5 Virtual Gym Module

For the implementation of the Virtual Gym, first, a preliminary study was carried out to identify the best underlying game engine. The following were considered:

- Mujoco: initially discarded due to its license, and a priori no official ROS integration. However, it is free since October 2021 and it will be open-source in 2022.
- IsaacSDK: discarded; several difficulties and bugs were found during the implementation of the tests.
- Pybullet: passed; in general, it is easy to use but with a less mature ROS integration.
- Gazebo: passed.

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- Unity: in general, very powerful and realistic, but with less virtual sensors available.

The deeper study of simulators was narrowed down to Pybullet, Gazebo and Unity. This study focused on the most important characteristics for the ACROBA project, i.e., usability for deep reinforcement training (parallelization capabilities, scene control, domain randomization), ROS compatibility, general usability, availability of sensors and actuators, etc. Quick experiments were done targeting each of the aforementioned characteristics and a comparison table was filled in order to have a standardized evaluation. This process required several meetings with the involved partners.

Next, since the decision was not clear, a parallel double implementation was done with Gazebo and Unity, focusing on a simplified IKOR scenario covering pick and place for small electronic components. The final decision has been to focus on the Unity engine; the following insights have converged in that decision:

- Gazebo seems to have a poorer performance on grasping and collision checking capabilities than Unity.
- Gazebo has a very good native interface with ROS, but Unity offers a very modern and nice integration with dockerized ROS.
- While Gazebo can be extended with C++ plugins (e.g., for domain randomization), Unity can be extended with C# scripts, too.
- Both engines allow for robot and scene definitions with URDF standards; additionally, Unity has a comfortable GUI with which objects can be manipulated.

Besides of that, a general architecture was defined for the Virtual Gym, as well as the interfaces with the Deep Reinforcement Learning module (T2.6) and the Perception & Action modules (T2.2). That architecture is agnostic to the underlying engine.

The simplified IKOR scenario served as a playground for the virtual generic cell implementation, which is the current short-term goal. That cell is being implemented following the definitions in WP3.

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Finally, meetings have been carried out with all pilot owners to better analyze the scope of the Virtual Gym for each of them. The goal has been to decide what to simulate, with which resolution, and what to provide specifically to the Deep Reinforcement Learning algorithms. We defaulted to the following logic: anything which is not handled by T2.6 (DRL) will be tackled by T2.2 (Perception & Action), and any sequences or prior knowledge need to come from the Task Planner (T2.3); additionally, T2.5 should provide the most realistic possible simulations for all operations learned by T2.6 using off-the-shelf engines. For each pilot, each operation was discussed in terms of the aforementioned goals. Although the short- term objective within T2.5 is to deliver a virtual generic cell, we consider that it is essential to bear in mind the particularities of the pilots early in the design.

2.4.6 Deep Reinforcement Learning Module

A general architecture for the Deep Reinforcement Learning (DRL) module was designed, that can be seamlessly integrated in the ACROBA architecture and especially with the Virtual Gym module.

After several meetings with the partners and a series of iterations, the preliminary version of the architecture for the DRL module was generated:

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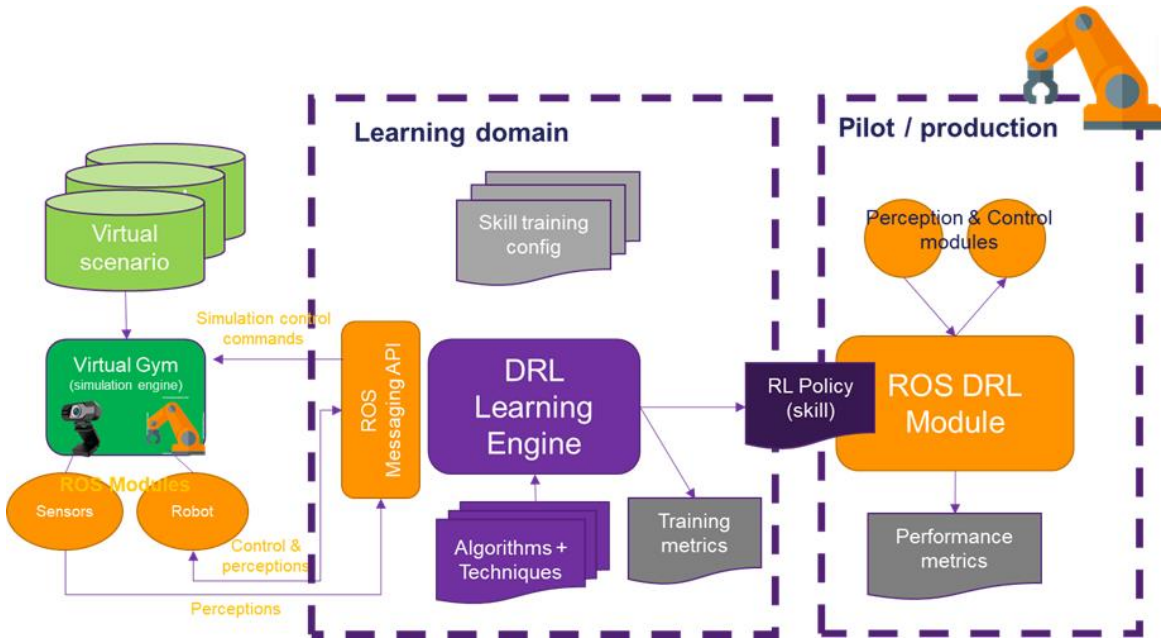
Figure 7 - Deep Reinforcement Learning Module Architecture



The architecture includes communication interfaces via ROS, both with the Virtual Gym module (simulation engine) and with the real infrastructure, assuring the conformity with the ACROBA platform. At an internal level, the simulation environment will be wrapped using an OpenAI Gym compliant interface, so existing algorithms and Reinforcement Learning libraries publicly available can be easily integrated.

Additionally, a study and basic analysis of these different Reinforcement Learning libraries was carried out. These libraries provide implementations of techniques and algorithms suitable for the goals of the use cases analysed in ACROBA.

The following table is an excerpt of the analysis of the libraries:

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Table 1 – Comparison of different DRL libraries

	Libraries	Pyqlearning	KerasRL	Tensorforce	RL_Coach	TFAgents	Stable Baselines RL Baselines3	MushroomRL
DRL algorithms	**Q-Learning**							+
	Deep Q-Learning (DQN)	+	+	+		+	+	+
	DQN Epsilon Greedy	+						
	Double DQN		+	+	+	+		
	Dueling DQN		+	+	+			
	Deep Deterministic Policy Gradient (DDPG)		+	+	+	+	+	+
	Soft Actor Critic				+	+	+	+
	Trust Region			+			+	+

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	Policy Optimization (TRPO)							
	Proximal Policy Optimization (PPO)			**+**	**+**	**+**	**+(1+2)**	**+**
	GAIL						**+**	
	…							
Policy networks support (default/customized)							+++ (Mlp, MlpLstm, MlpLnLstm, Cnn, CnnLstm, CnnLnLstm)	
Documentation		---	+++	+++	+++	++	+++	
Code readability and customization		---	+++	++	++	+++	+++	
Supported environments		-	Open AI Gym	OpenAI Gym, OpenAI Retro and DeepMind Lab	OpenAI Gym, ViZDoom, Roboschool, GymExtensions, PyBullet, CARLA, ..	Agnostic for environments	OpenAI Gym +Mujoco +Gazebo+ODE +ROS1/2	OpenAI Gym, DeepMind Control Suite, MuJoCo

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Logging support	No	Yes	TensorBoard	Multiple	Yes	TensorBoard	TensorBoard
Vectorized environment support	No	Yes	Yes	Yes	Yes	Yes	Yes
Updates and maintenance	---	---	+++	+++	+++	++	+++

The most suitable algorithms provided by the libraries were also analysed.

Meetings were held with the partners involved in the development of the Virtual Gym module in order to analyse the features of different alternatives for virtual environments and their suitability for the DRL learning process. The most promising were Gazebo and Unity3D (which has recently incorporated ROS integration).

On the other hand, an experimental set up with a robotic arm was designed and a “mirror” virtual gym environment to replicate a basic use case, with the purpose or pre-evaluating the suitability of the architecture.

The following image displays in parallel that set-up, both in the real and virtual scenario with the robotic arm behaving exactly in the same way:

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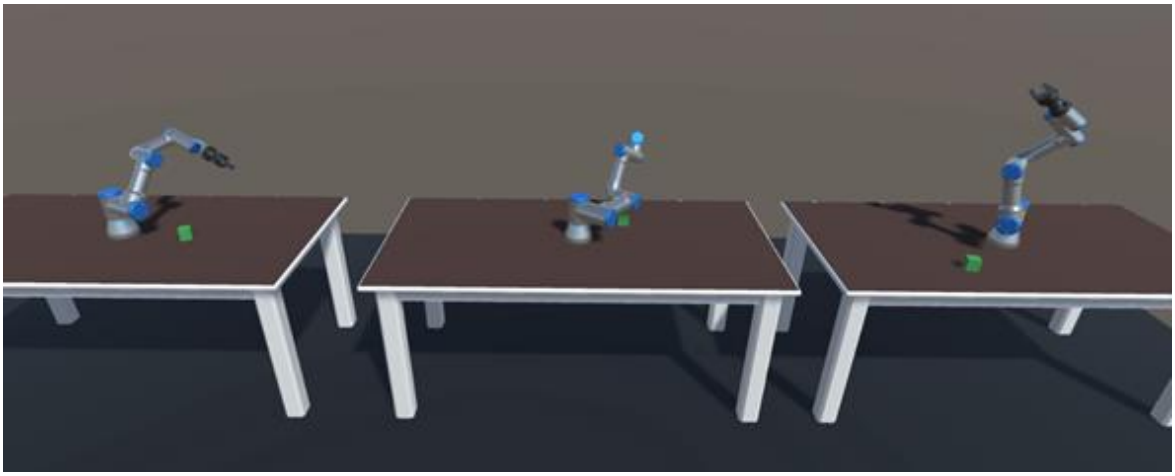
Figure 8 - Virtual and Real-World Robotic Setups

Training scenarios with multiple robotic arms to explore parallel learning were also designed and tested, as illustrated in the following image.

Figure 9 - Example of DRL Training for Object Grasping



Finally, as one of the distinct features that DRL can provide is training a robotic arm to avoid obstacles while performing a task, some set-ups were created to explore the most suitable algorithms and techniques for this purpose. The following figure shows one of these scenarios with the robotic arm avoiding several obstacles to reach a target:

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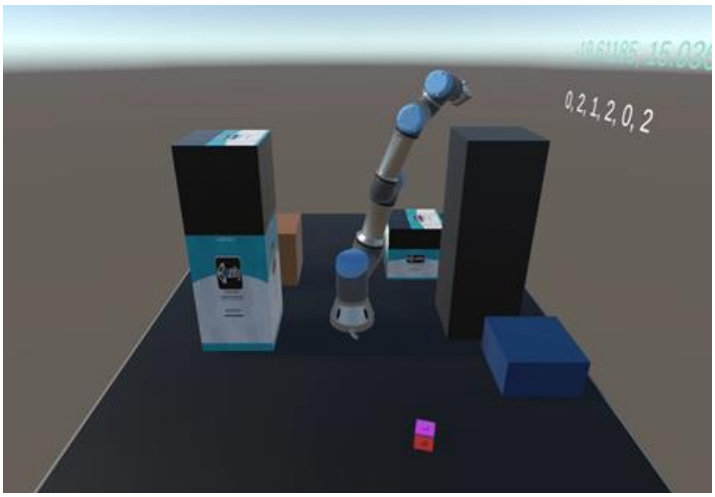
Figure 10 - Example of DRL Training for Obstacle Avoidance



Since testing DRL algorithms is very time consuming and requires a certain knowledge about algorithms, neural networks or hyperparameters tuning, in order to facilitate experimentation an "experiment training launcher" is being designed to automate the process of trying different algorithms, techniques and parameters while searching for the optimal combination. This launcher is designed in Python and compliant with the OpenAI Gym interface as the DRL module.

Along with the partners involved in the development of the Virtual Gym module, several meetings took place with the use cases to understand better the different activities involved in the robotic environment and identify which of these activities could be appropriate candidates to apply DRL instead of traditional mechanisms / algorithms.

2.5 Definition of skills for proposed use cases

The proposed ACROBA architecture is based on the execution of skills. A skill can be understood as a series of simple actions that, executed together, can lead to the execution of a specific task within a use case.

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According to the specification of the skills themselves, they can be divided into generic skills, corresponding to those activities that are commonly performed in all use cases and in robotics applications in general, and specific skills, which, as their name suggests, are skills particularised to a specific activity within a use case.

Skills, in turn, are based on the execution of low-level functions called primitives.

For a more formal definition of what a skill is and its structure in the context of the ACROBA project, please refer to deliverables D1.1 and D1.2.

This document contains the definitions of the skills required for each use case, together with their primitives. The primate functions will also define the ROS data format needed for each of them. This information has been provided by the partners in charge of the use cases, that is, end users and technological centres associated. At this stage of the project these skills have been designed at a theoretical level, and they could implement little variations when implemented in the real use case setup.

Depending on the use case, the number of generic and specific skills will vary.

3 Formal definition of use cases

3.1 Medical devices pilot line

3.1.1 Brief description

This use case focuses on the manufacture of plastic medical devices through 3D printing. The aim is to automate the production line using robotics, to optimize the production process of the plant.

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It is proposed to use a 6-DOF robot with a minimum load capacity of 5 kg, a maximum total weight of 50 kg and a minimum repeatability of 0.2 mm, due to the type of medical device parts that are manufactured in STERIPACK (STER).

RGB-D cameras will be used to locate the medical devices parts and their subsequent post-processing (deburring).

The robot will also be equipped with a wrist force sensor to compensate for any inaccuracies that may occur in the process.

It is also contemplated the use of self-alignment jigs for restricting the movement of the parts under processing operations.

A detailed description of this use case can be found on D4.1, already submitted.

3.1.2 Hardware requirements

The use case proposed by STER requires mainly two types of sensors to provide the process robots with cognitive capabilities. These two elements are a 3D camera and a force sensor for the robot tool.

The 3D camera will provide colour images and calibrated point clouds to enable analysis of the environment in the camera's viewing area. This environment perception capability will be used for object localisation and recognition tasks as well as for object inspection.

On the other hand, the force sensor placed on the robot's tool, in this case a gripper, will allow the control of the manipulation of the manufactured elements, which is necessary due to their fragility.

Taking into account that the sensors to integrate must be compatible with ACROBA architecture (based on ROS), the following is a list of proposed hardware devices to be integrated in the platform. In parenthesis, ROS message types published:

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- 3D cameras (sensor_msgs/Image, sensor_msgs/PointCloud2): Ensenso N45, Gocator 3210, Intel RealSense D455, Zivid One+, Zivid Two, Photoneo PhoXi m.
- Force Sensor (std_msgs/float64): Schunk force sensors, RobotIQ FT300-S

3.1.3 Skill definition

The list of skills defined by Steripack for their use case are the following, all of them related to the parts they need to manipulate:

Figure 11 - Steripack´s use case skills

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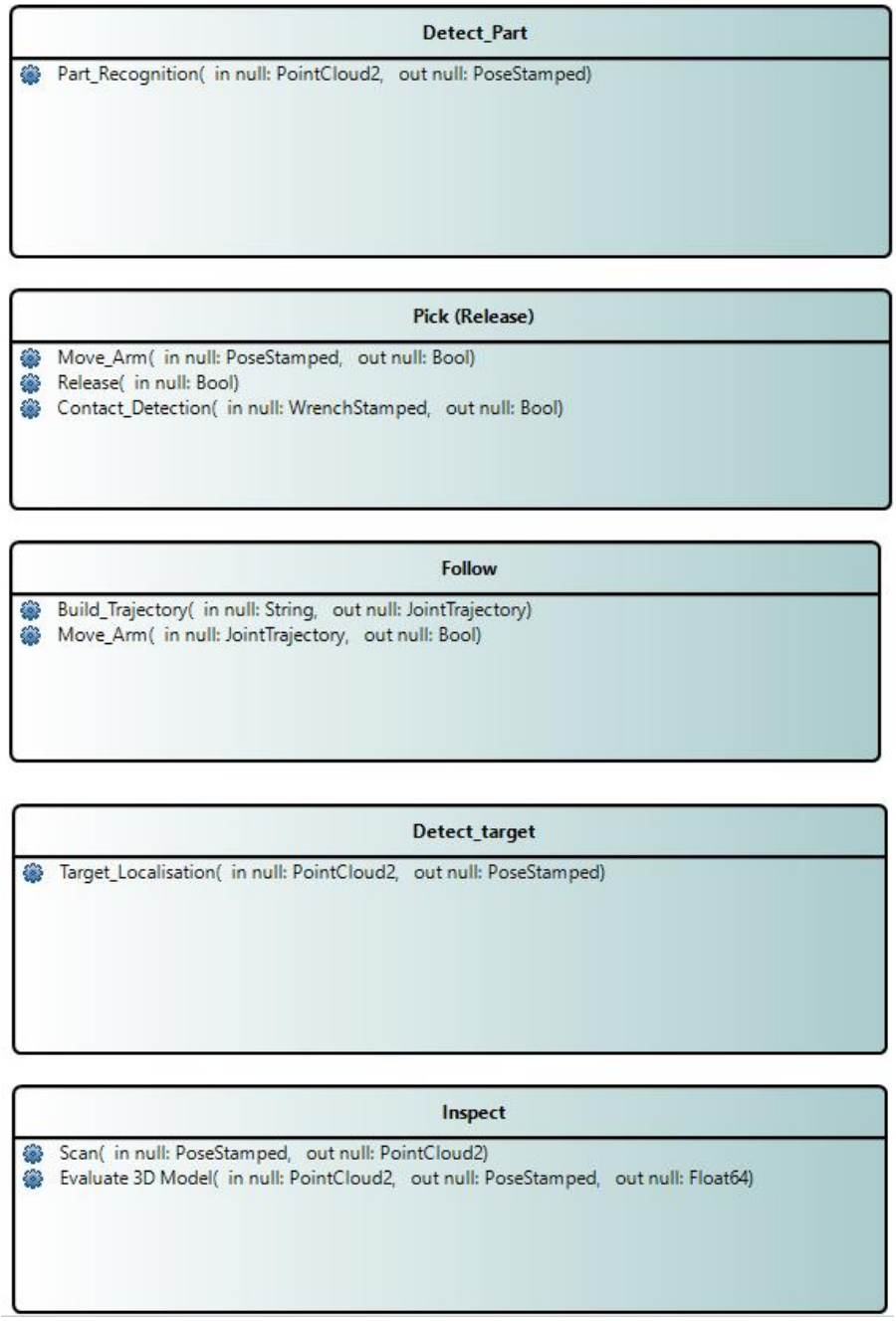

3.1.4 Task planner

The behaviour trees created by the task planner are as follows:

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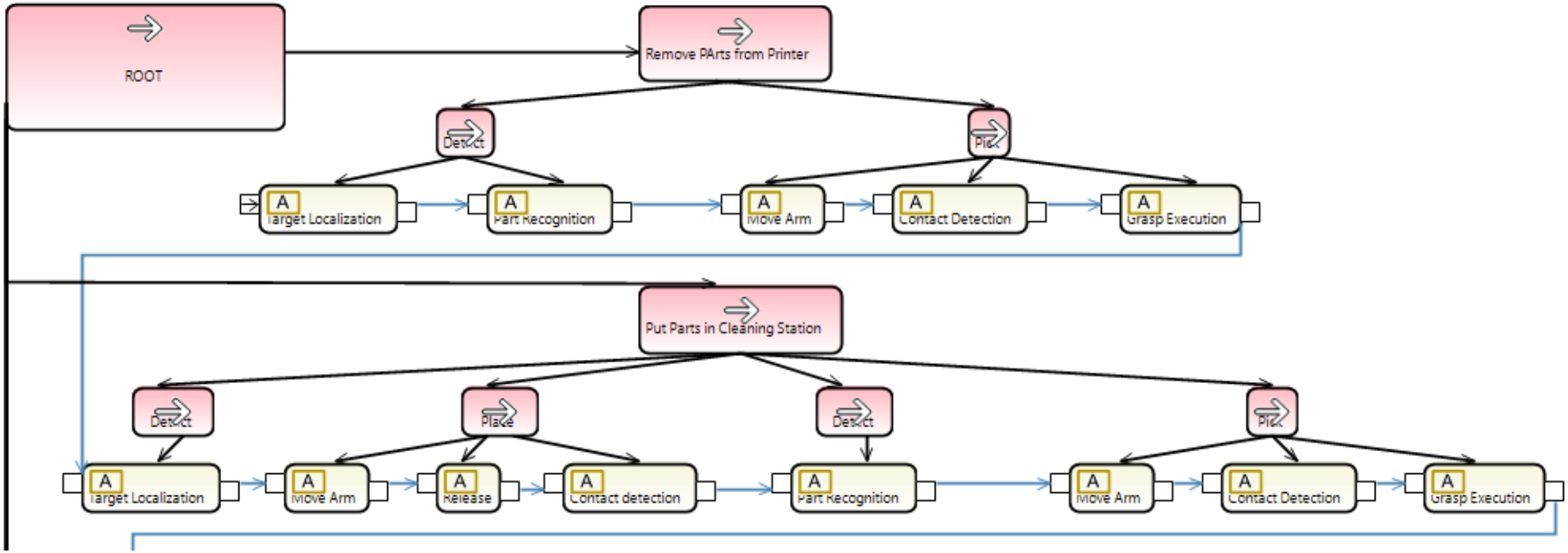
Figure 12 - Steripack´s general Behaviour Tree for the Task Planner



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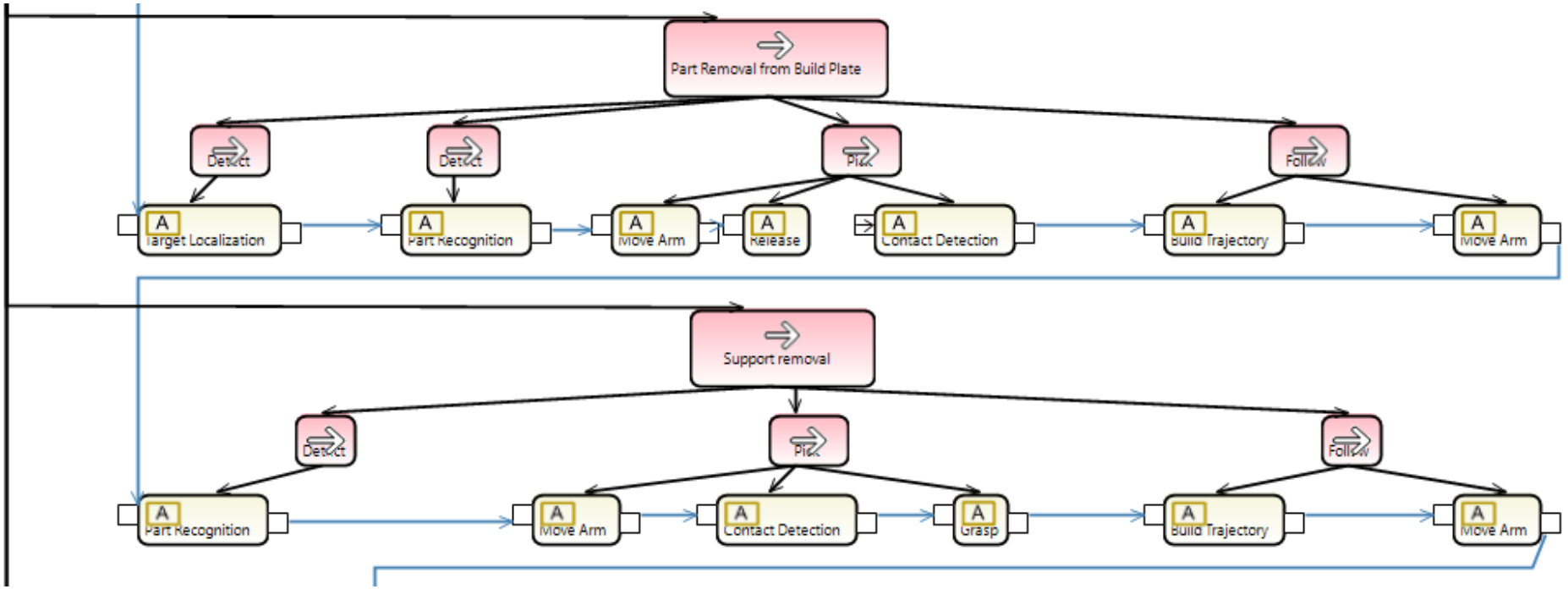
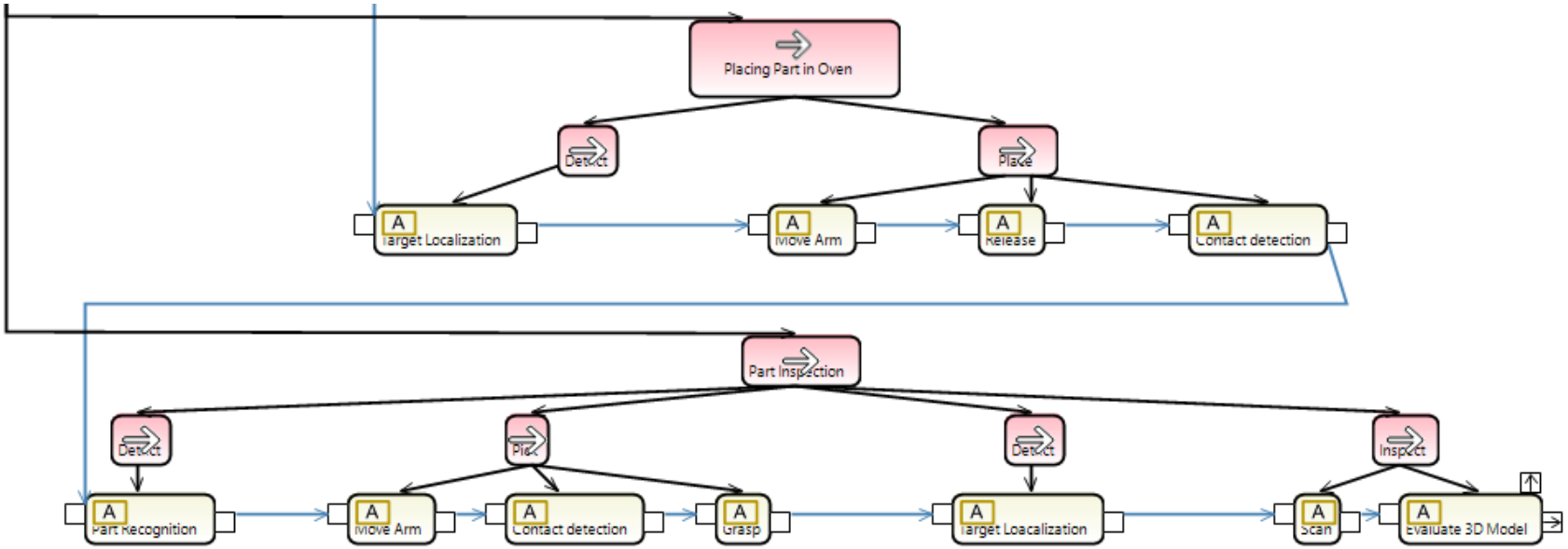


The ACROBA project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101017284.



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3.2 Plastic Pilot Line 1 (MOSES)

3.2.1 Brief description

MOSES is a Spanish company specialized in the production of plastic parts, more specifically, contenur oval containers in this use case. The variability of these containers demands the development of specific robot trajectories frequently. This process is very limiting for manufacturing flexibility.

For this process, the robotic cell layout to be used in ACROBA is composed of a Yaskawa GP50, with a 1000 x 2000 worktable. The working area is also equipped with several cameras.

More information related to this use case can be found on D4.2.

3.2.2 Hardware requirements

In the case of MOSES, several computer vision devices are needed according to the use case specifications.

Fixed cameras will be needed to track trajectories and to collect overall data in the shopfloor. In addition to these cameras, cameras mounted on the robots will be of use, to check positions of different elements and size deviations of the different parts of the products. Both fixed and mobile cameras can be stardard RGB cameras or RDB-D cameras (color +depth information). A list for these devices can be the following:

- 3D cameras, RGB-D cameras (sensor_msgs/Image, sensor_msgs/PointCloud2): Ensenso N45, Gocator 3210, Intel RealSense D455, Zivid One+, Zivid Two, Photoneo PhoXi m.
- RGB cameras (sensor_msgs/Image): Industrial cameras from Allied Vision (Manta G-504), Basler (Ace 2 pro), Dalsa (Boa models) or IDS.

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3.2.3 Skill definition

In the case of this pilot line from MOSES, these are the skills defined with the help of AITIIP, the technological centre supporting this use case.

Figure 13 - MOSES´ skill definition set

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3.2.4 Task planner

The behaviour trees created by the task planner can be found in the following pages.

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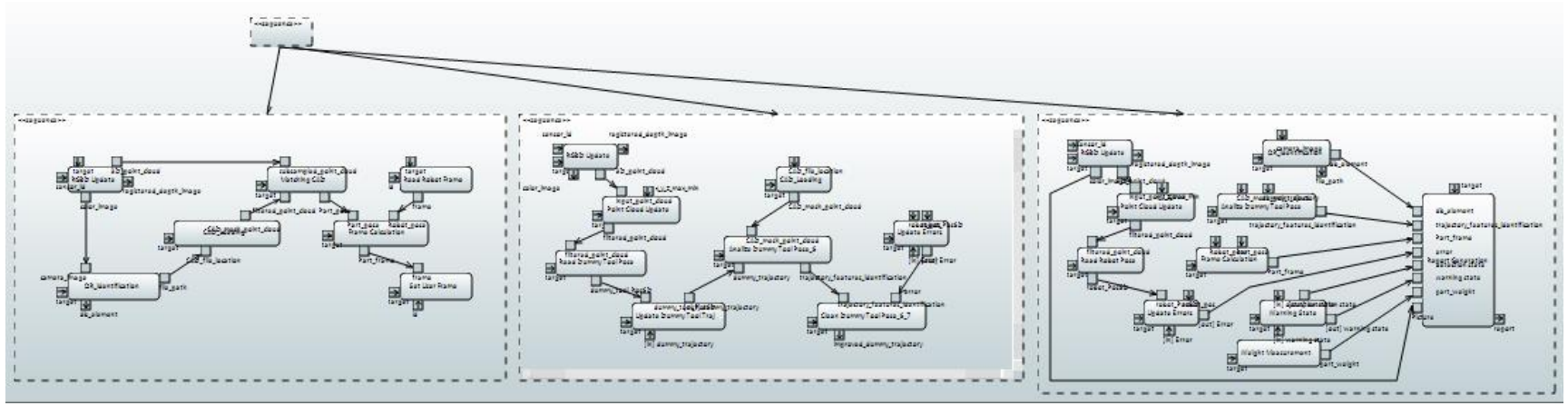
Figure 14 - MOSES´ general Behavior Tree for the Task Planner



These actions are now presented more in detail:

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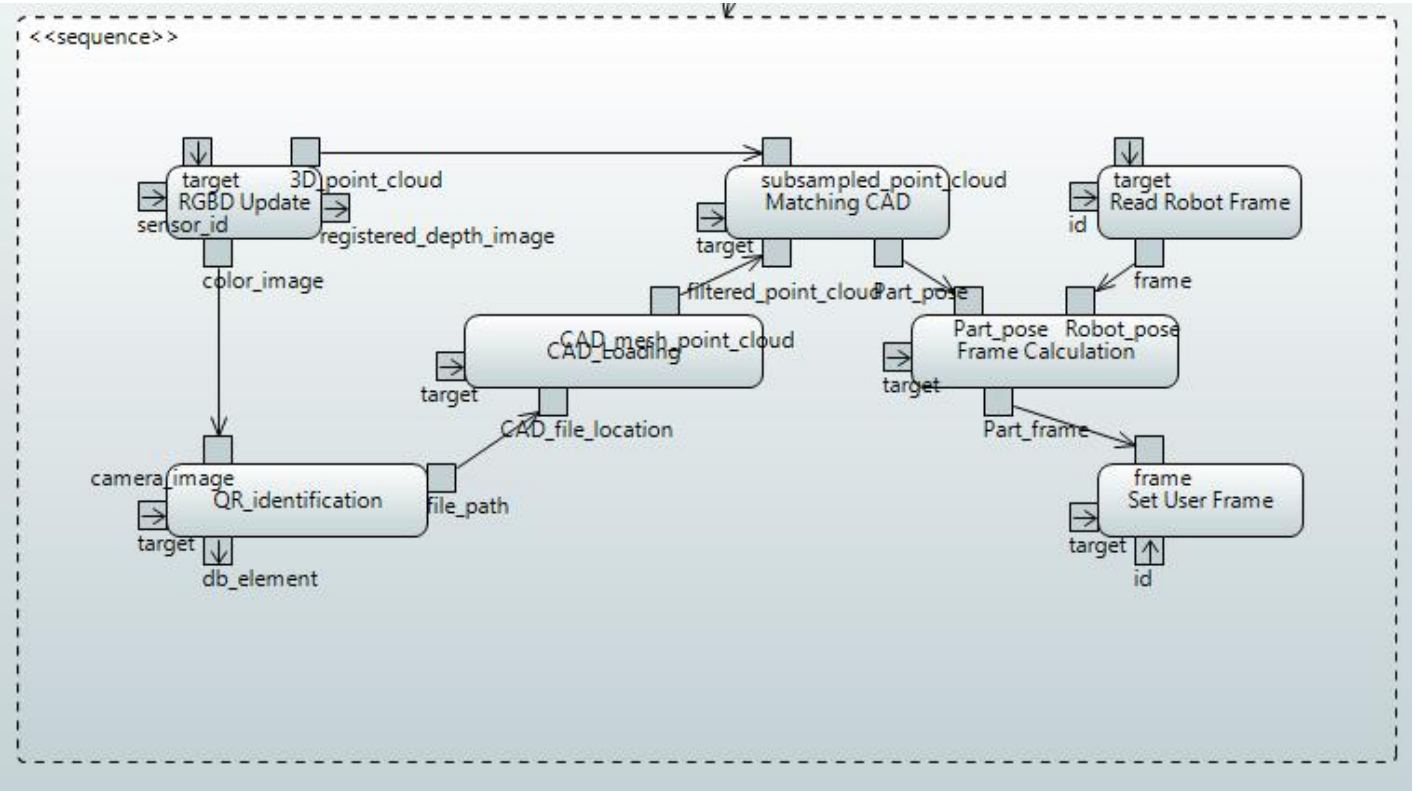
Figure 15 - MOSES´ Behavior Tree sequences in more detail



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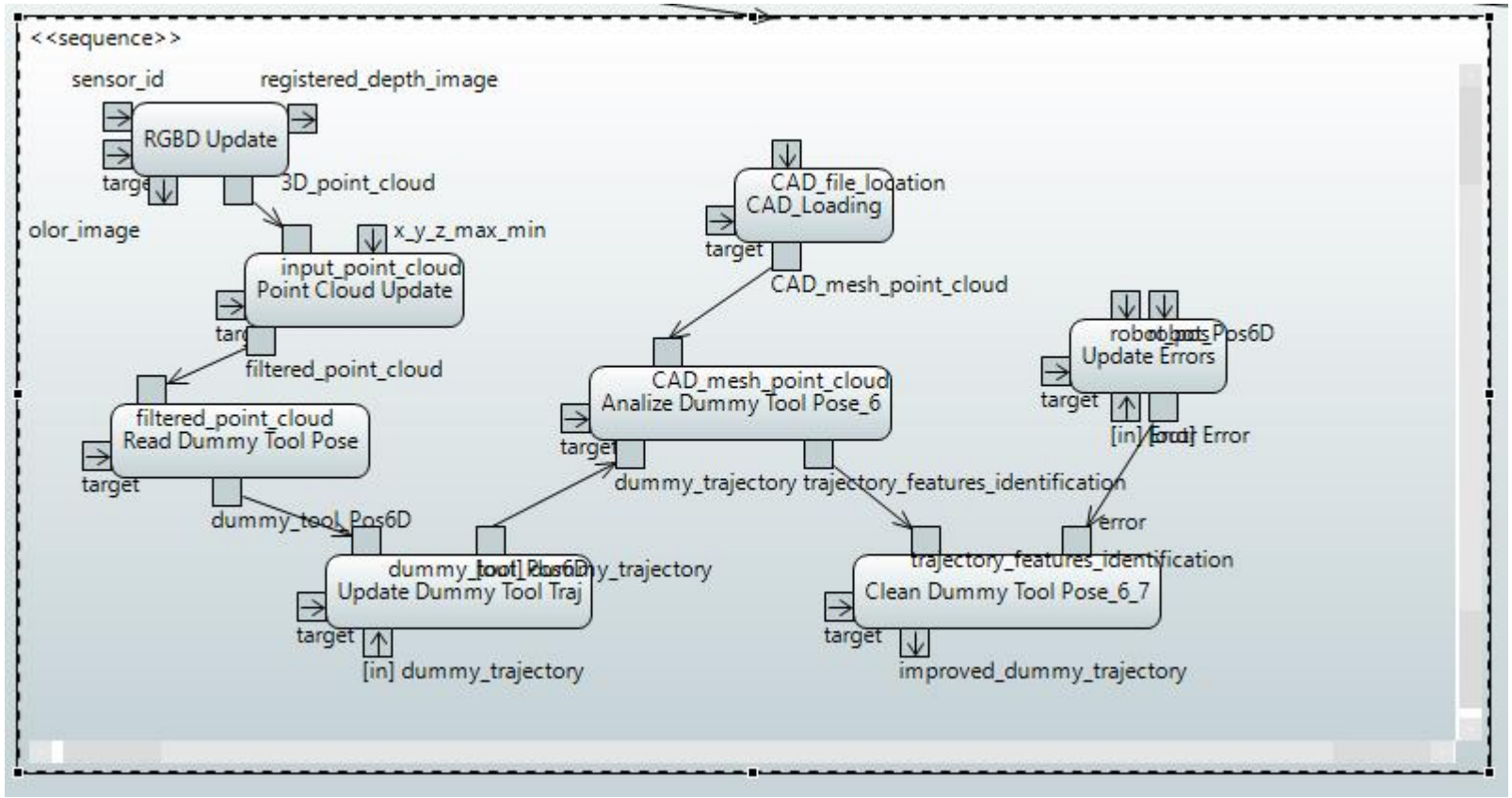
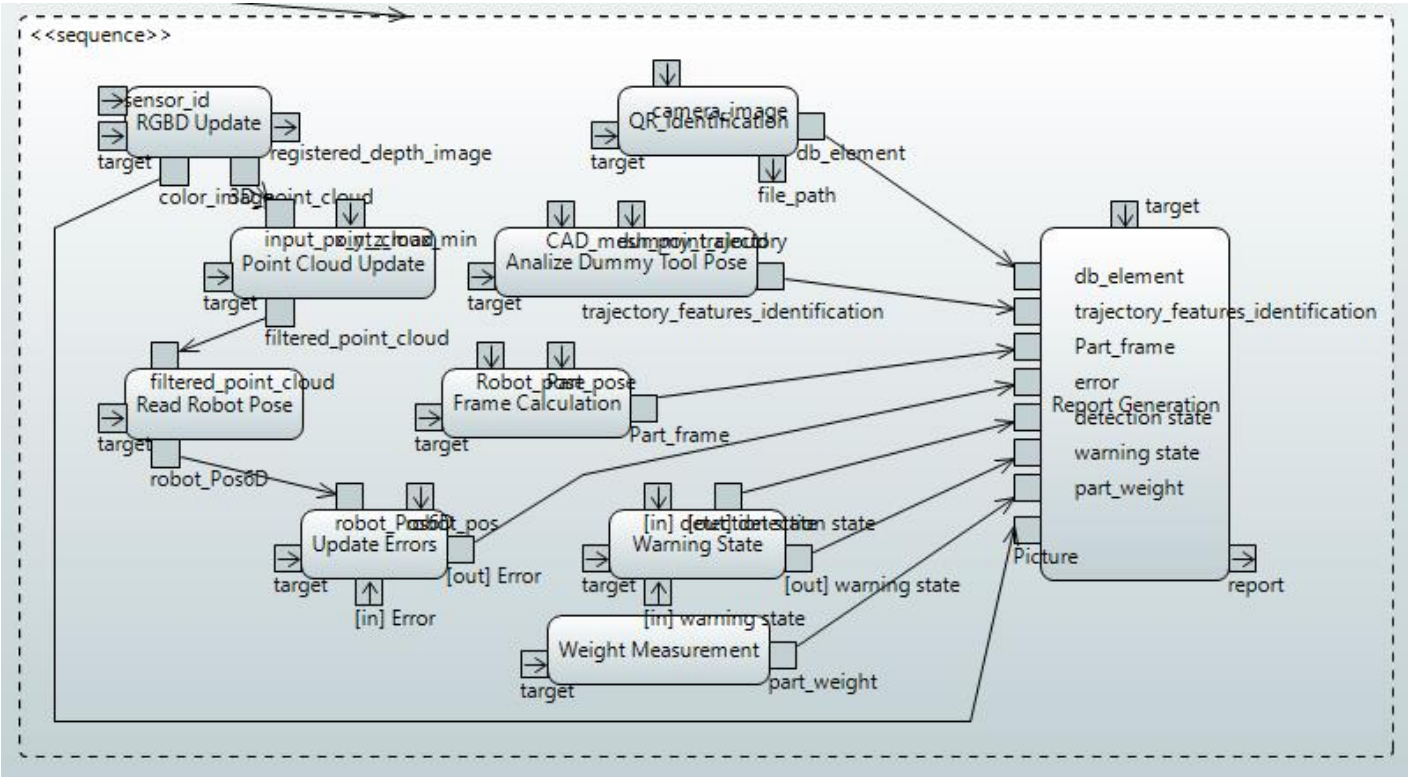


The ACROBA project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101017284.



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3.3 Plastic Pilot Line 2 (CABKA)

3.3.1 Brief description

CABKA fabricates plastic pallets. Most of them need a rework on them, mainly for deburring tasks. Depending on the type of pallet, another type of reworks to carry out are assembly, welding or gluing. ACROBA platform will focus on deburring tasks.

9The robotic cell in CABKA is composed by two Kuka robots, several industrially certified safety systems (doors, curtains), milling tools for the robot, conveyors and several types of sensors.

This use case is explained more in detail in D4.2.

3.3.2 Hardware requirements

3D scanning of the products (pallets) will be carried out manually using specific equipment.

For the deburring operation itself, two sensors will be needed; a 3D camera, to identify burrs, and a force sensor, to control force applied by the burr removal tool.

According to previously mentioned models for this hardware, a selection for this use case could be the following:

- 3D cameras (sensor_msgs/Image, sensor_msgs/PointCloud2): Ensenso N45, Gocator 3210, Intel RealSense D455, Zivid One+, Zivid Two, Photoneo PhoXi m.
- Force Sensor (std_msgs/float64): Schunk force sensors, RobotIQ FT300-S

3.3.3 Skill definition

The skills needed in this use case are the same of the ones used in the MOSES use case, however, some of them have been updated with some more specific primitives for their correct adaption to this use case.

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Figure 16 - CABKA´s Skill definition set

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3.3.4 Task planner

The Behavior Trees, created by the task planner defining the execution of this use case can be found in the following figure. One important issue that must be taken into account in this specific case is that the general BT includes two actions that are executed outside the ACROBA platform, but they have been added for the general understanding of the process. These are “Pick & Place” and “Part Deburring” skills.

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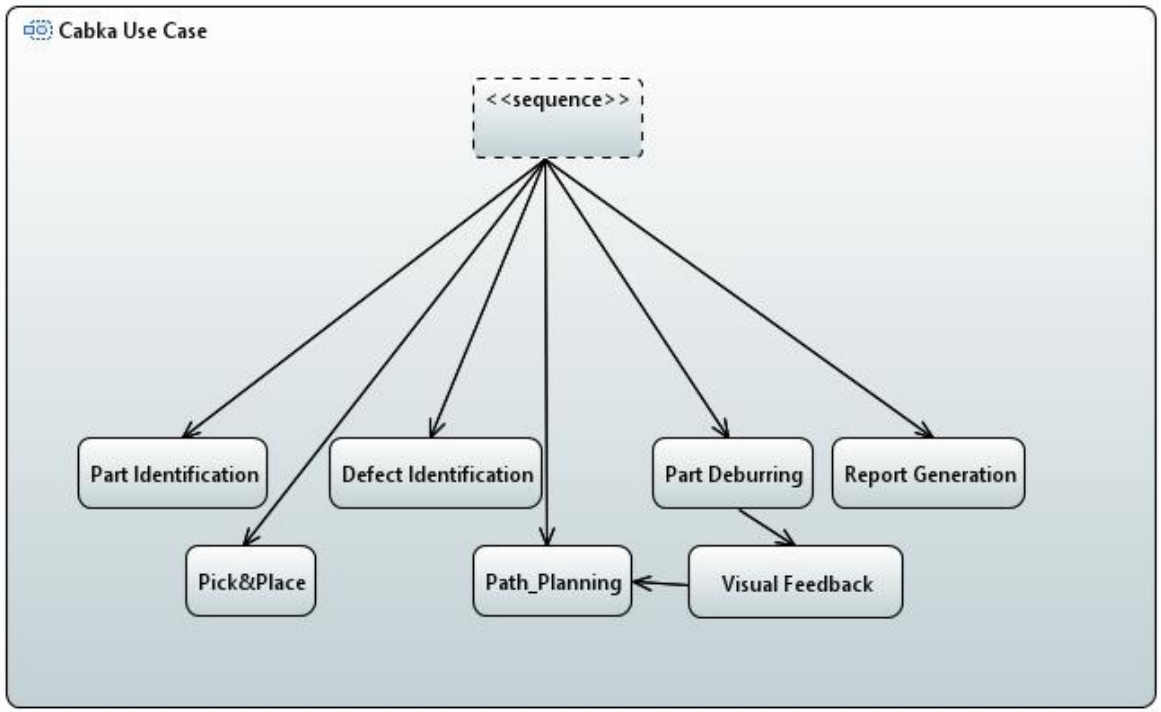
Figure 17 - Behavior Tree for CABKA´s use case.



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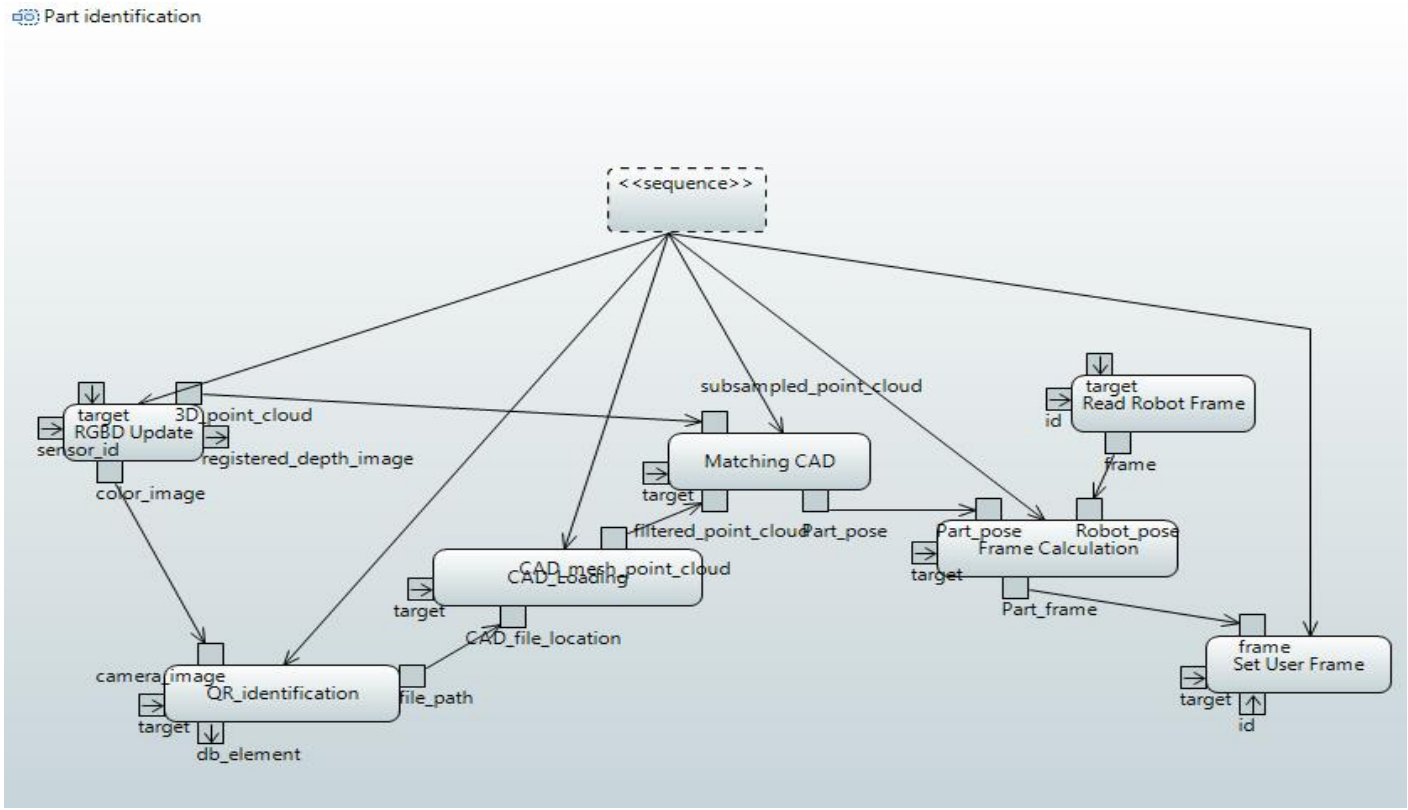
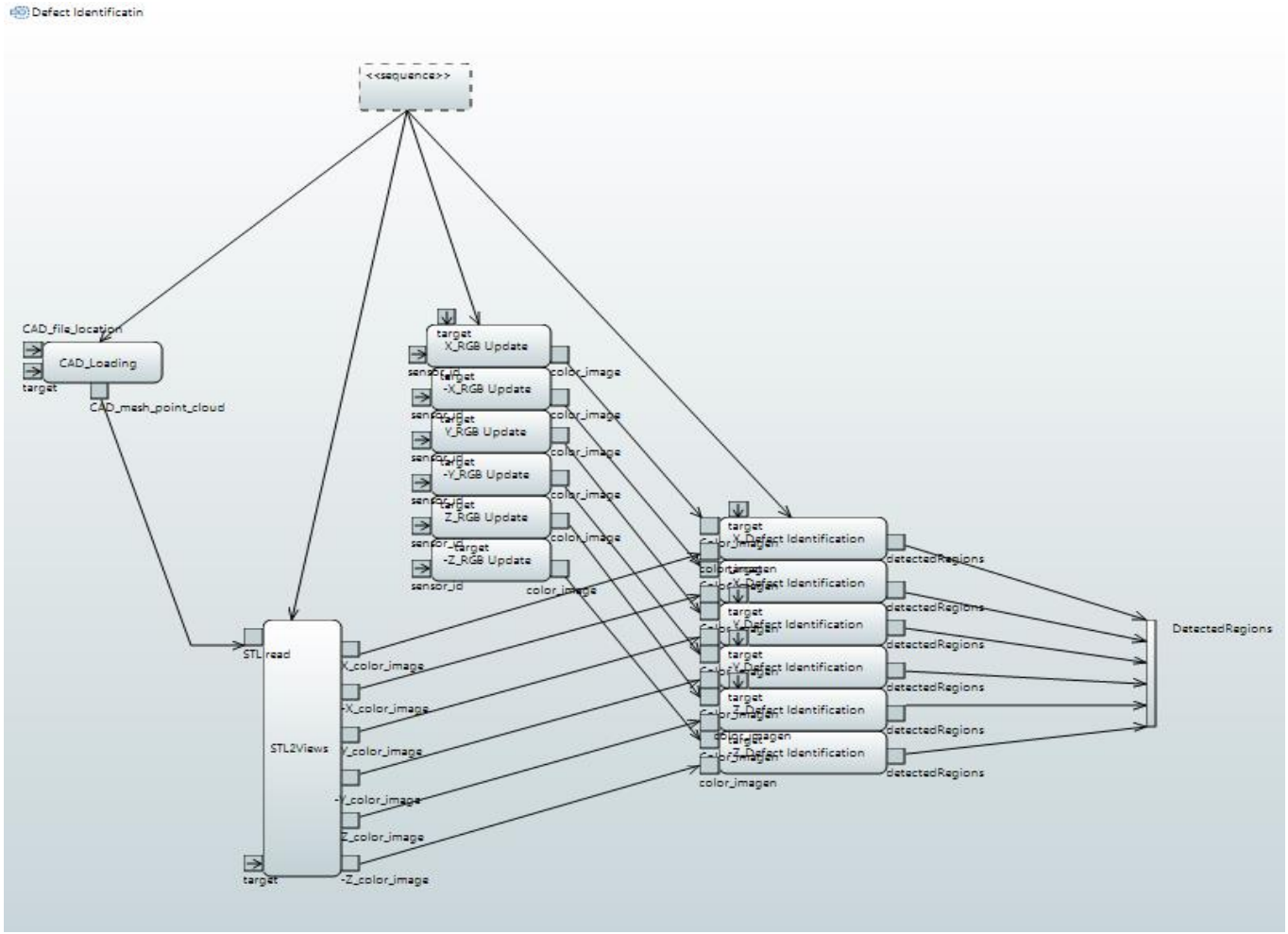
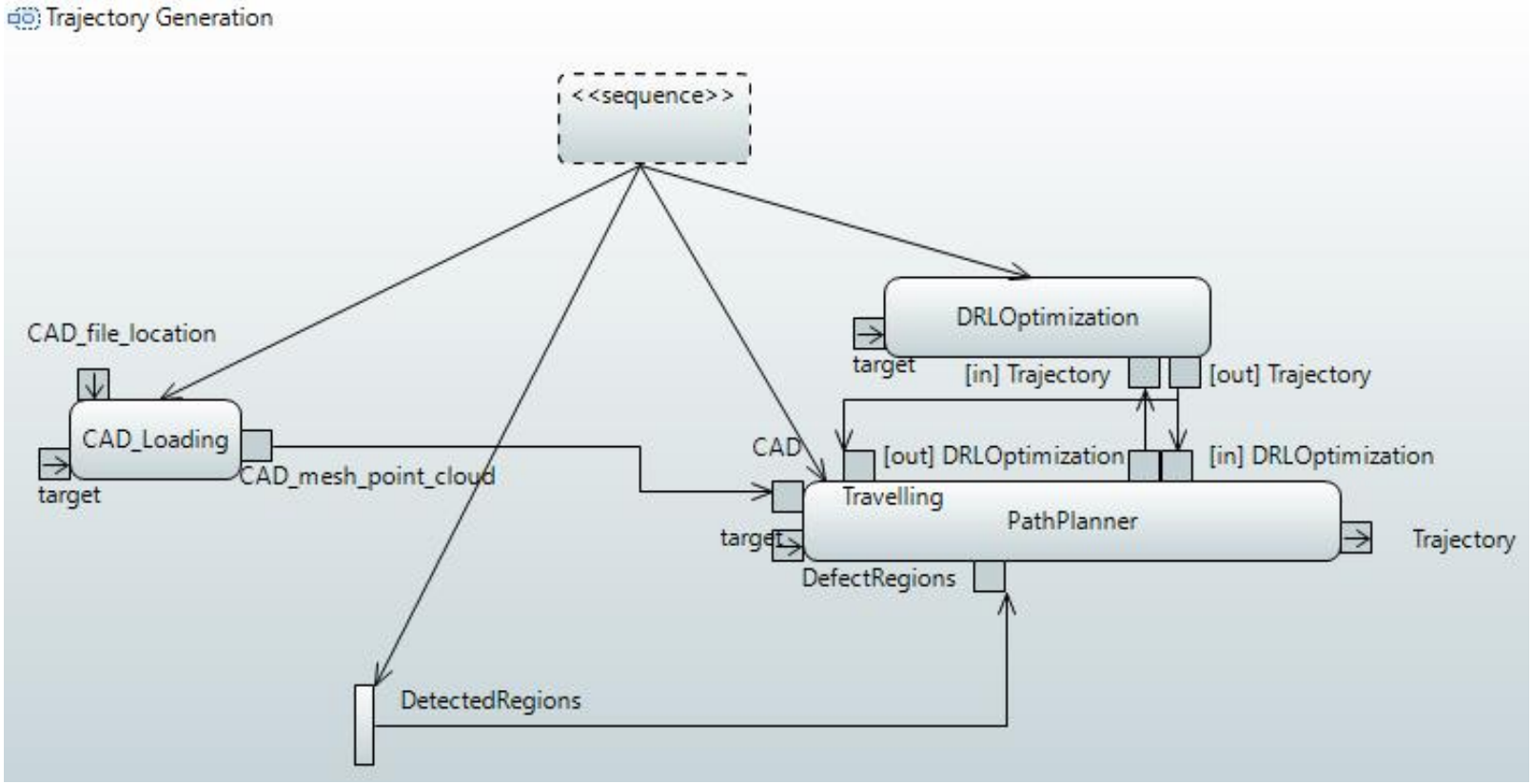


The ACROBA project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101017284.



The ACROBA project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101017284.



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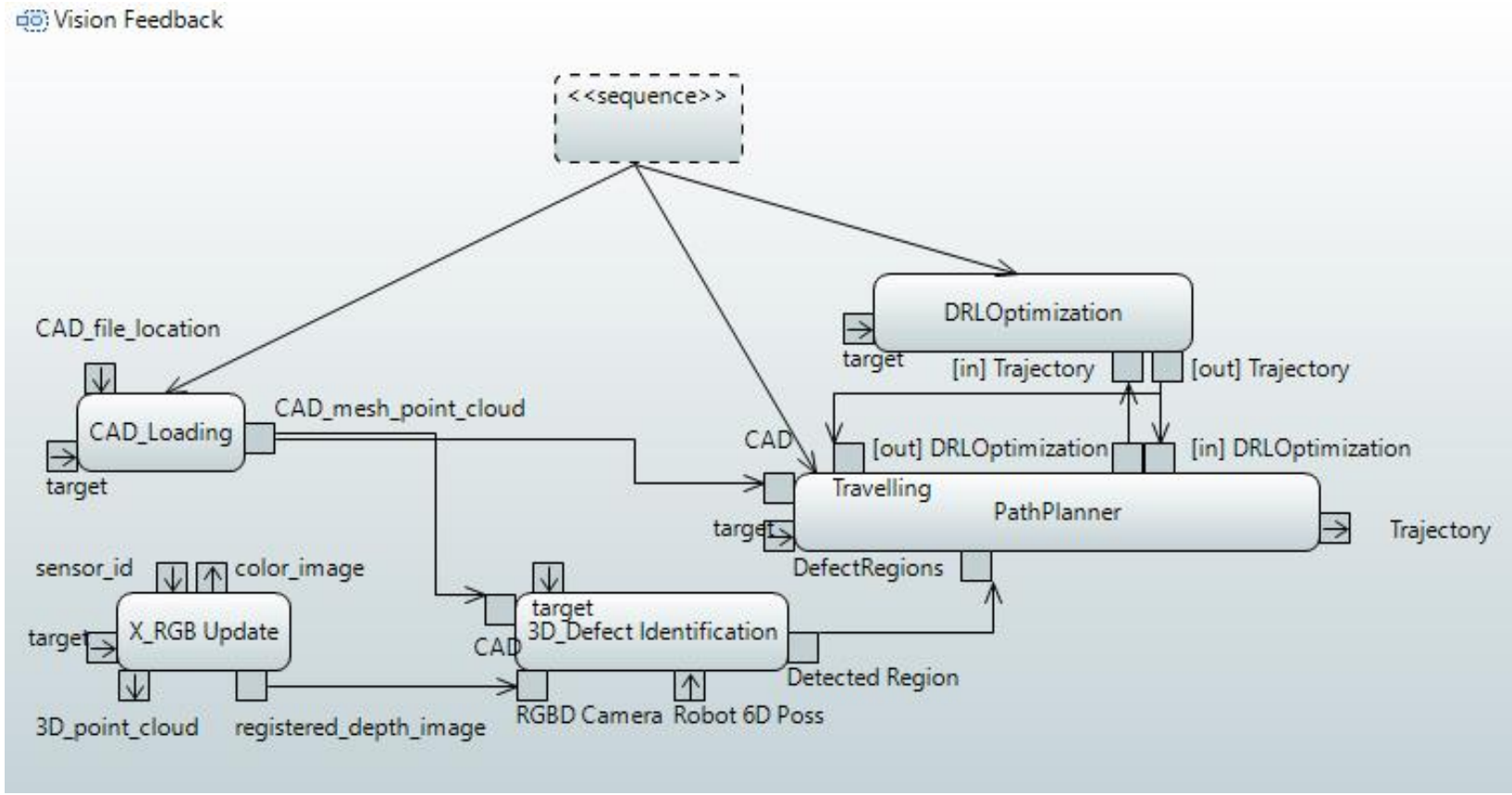

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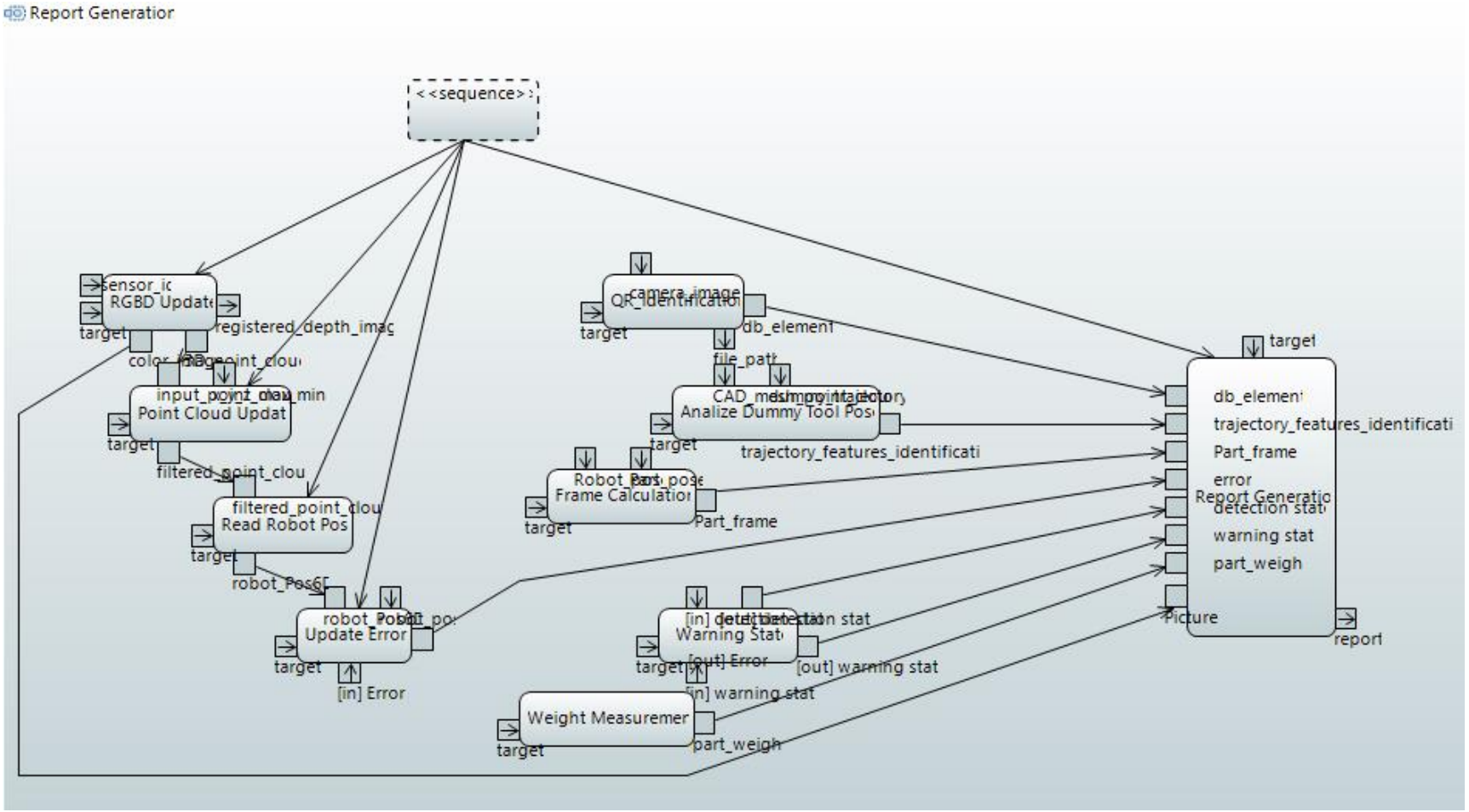

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3.4 Electronic components pilot line (IKOR)

3.4.1 Brief description

This use case is based on the IKOR pilot line. IKOR is a Spanish company specialized in the design and manufacture of electronic circuits (EMS), including complete supply chain solutions for world-leading industrial and technological companies. The use case for ACROBA consists on the assembly of small electronic components or PTHs (Pin-Through-Hole) on electronic boards or PCBs (Printed Circuit Board), which is currently done manually but expected to be transformed into a collaborative human-robot system through the ACROBA architecture. An additional challenge is the small size of the electronic components to deal with.

For the automation of this process there are currently two approaches that will be taken into account: a single or dual arm robot combined with a carrousel, or the use of a hopper system which spreads the PTHs on a vibrating conveyor belt.

The deliverable D5.1 explains all the details of this proposed use case.

3.4.2 Hardware requirements

In the use case provided by IKOR it is of vital importance the correct localization and grasping of the PTHs. Also the capacity for reading QR and bar codes is needed in this use case. Finally, and although this case is a collaborative application, the presence of human operators must be also monitored.

Taking into account all these requirements, the following hardware equipment is proposed.

- 3D cameras (sensor_msgs/Image, sensor_msgs/PointCloud2): Ensenso N45, Gocator 3210, Intel RealSense D455, Zivid One+, Zivid Two, Photoneo PhoXi m.
- Force Sensor (std_msgs/float64): Schunk force sensors, RobotIQ FT300-S.
- RGB cameras (sensor_msgs/Image): Industrial cameras from Allied Vision (Manta G-504), Basler (Ace 2 pro), Dalsa (Boa models) or IDS.

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- Photoelectric sensors (std_msgs/bool): Keyence SZ series safety laser scanner, SICK S300 safety light curtains

3.4.3 Skill definition

VICOM has helped IKOR with the definition of skills and the creation of the task planner.

The skills created for this use case are the following:

Figure 18 - Skill definition set for IKOR´s use case

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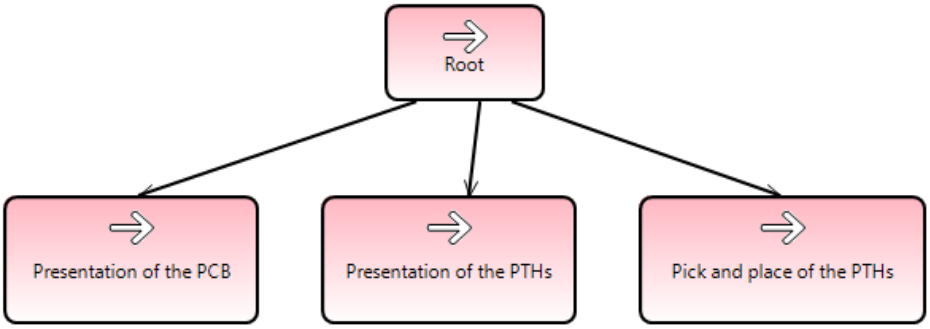
3.4.4 Task Planner

The behaviour tree is created by the task planner following a top bottom approach, defining the three main sequences to execute the complete task, and then these three main actions have been further defined.

Figure 19 - Behavior tree for IKOR´s use case



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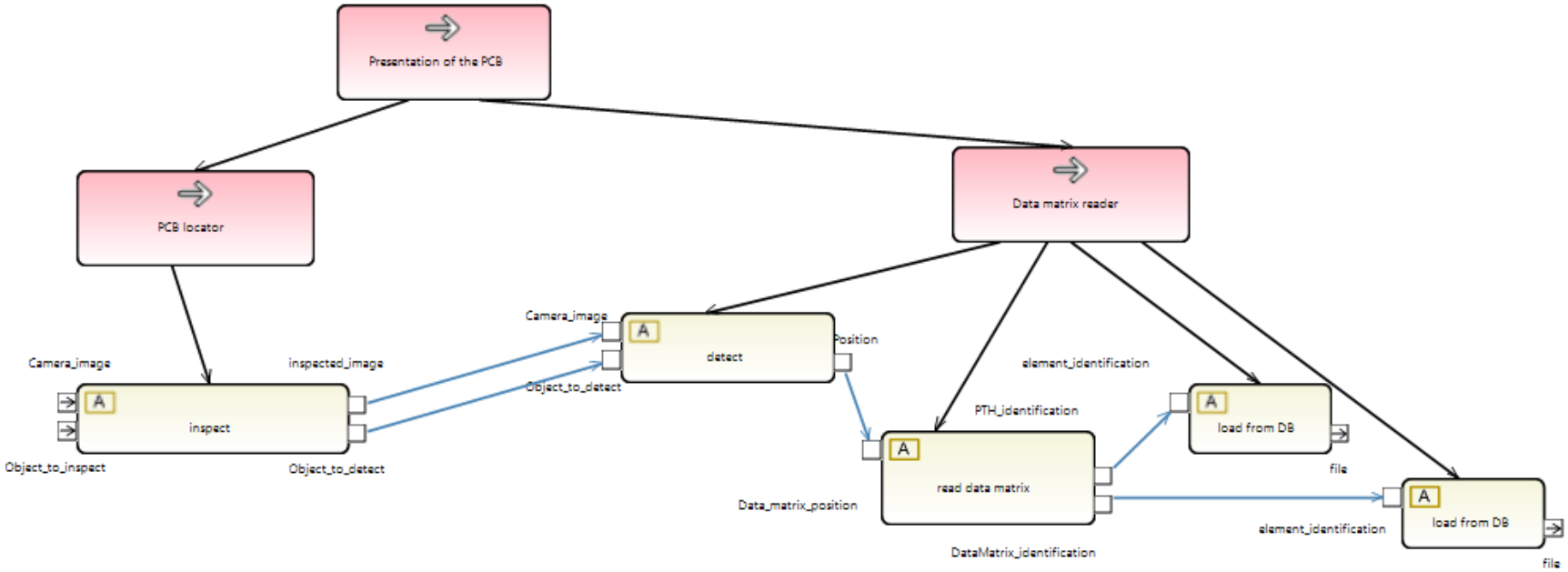
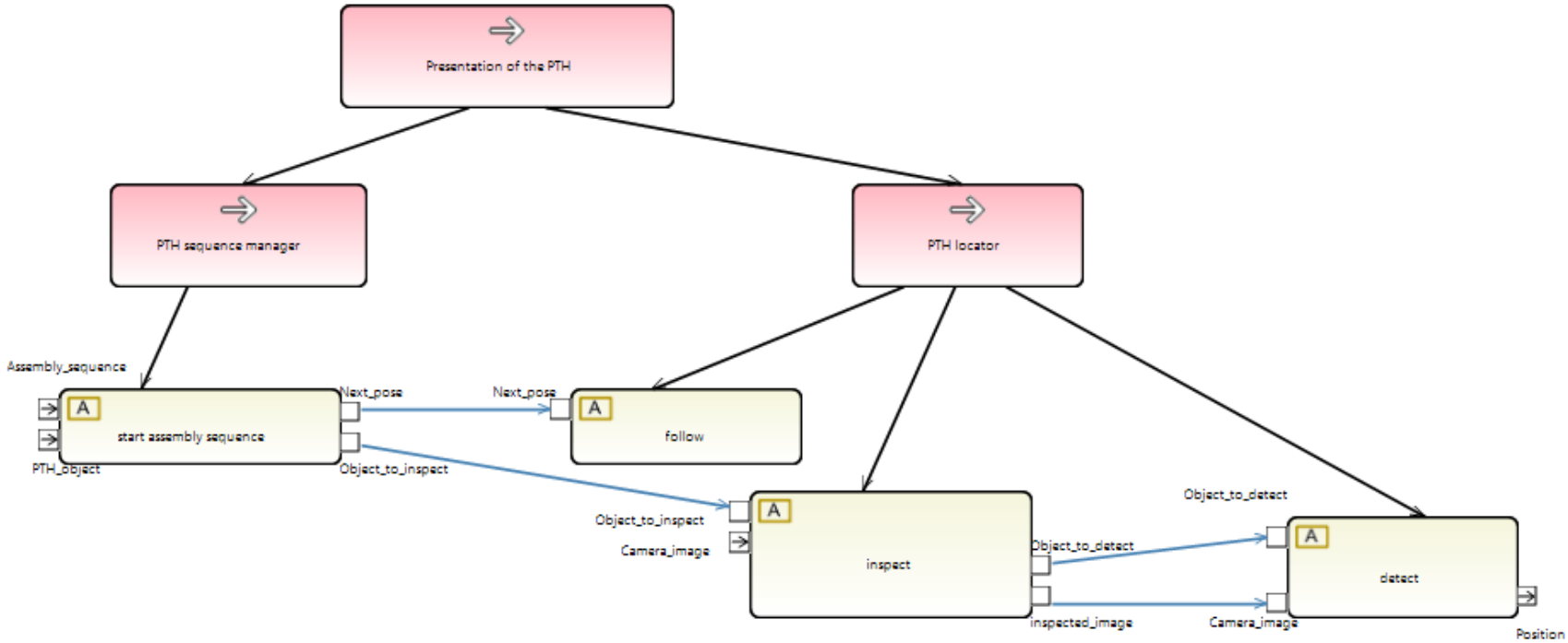


The ACROBA project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101017284.



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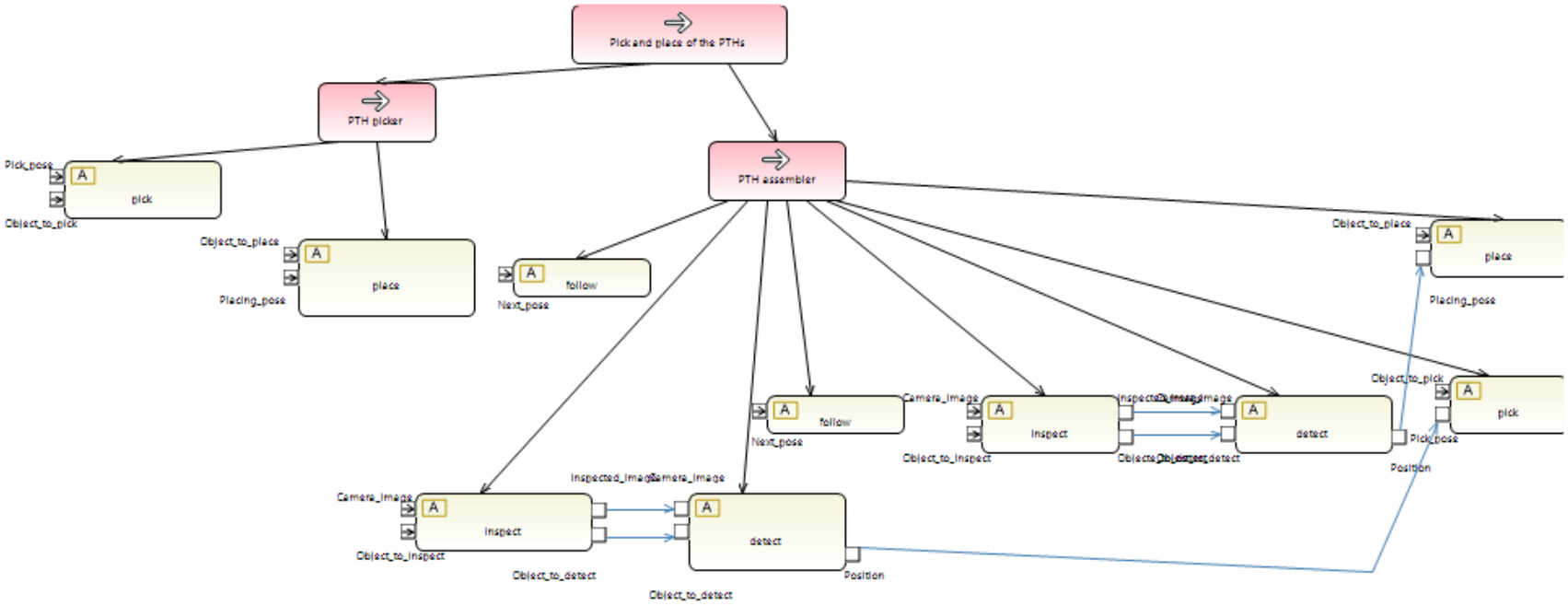

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3.5 Electric motors pilot line (ICPE)

3.5.1 Brief description

This last use case focuses on the automatic assembly of different types of components in electric motors.

Currently, the assembly of these elements is carried out in the ICPE company in a completely manual way, in three different lines: coil winding, slotless coils bonding and bonding of permanent magnets.

In this use case, the main objective to be achieved with the ACROBA architecture presented in this document is to increase the level of automation of the process, in such a way that the working conditions of the workers are improved, there is greater manufacturing flexibility and a uniform quality in all the units manufactured.

Detailed description of the use case is contained in D5.2.

3.5.2 Hardware requirements

In ICPE's use case many specific sensors related to magnetism and to electric motors are needed. In this case ICPE is still working on the selection of these equipment, taking into account their communication capabilities and the work needed for their integration in the ACROBA platform. Provided these sensors have an API (Application Programming Interface) for Linux, they could be easily integrated into the ACROBA platform.

Also, polarity sensors to detect the magnets' polarity, contact sensors to detect their correct placement or force sensors to press the coils or magnets on the stator are needed.

3D cameras will be used for location and quality control of the magnets inside the motors, and RGBD cameras will be needed for working place monitoring.

According to these necessities the tentative list of hardware needed is as follows:

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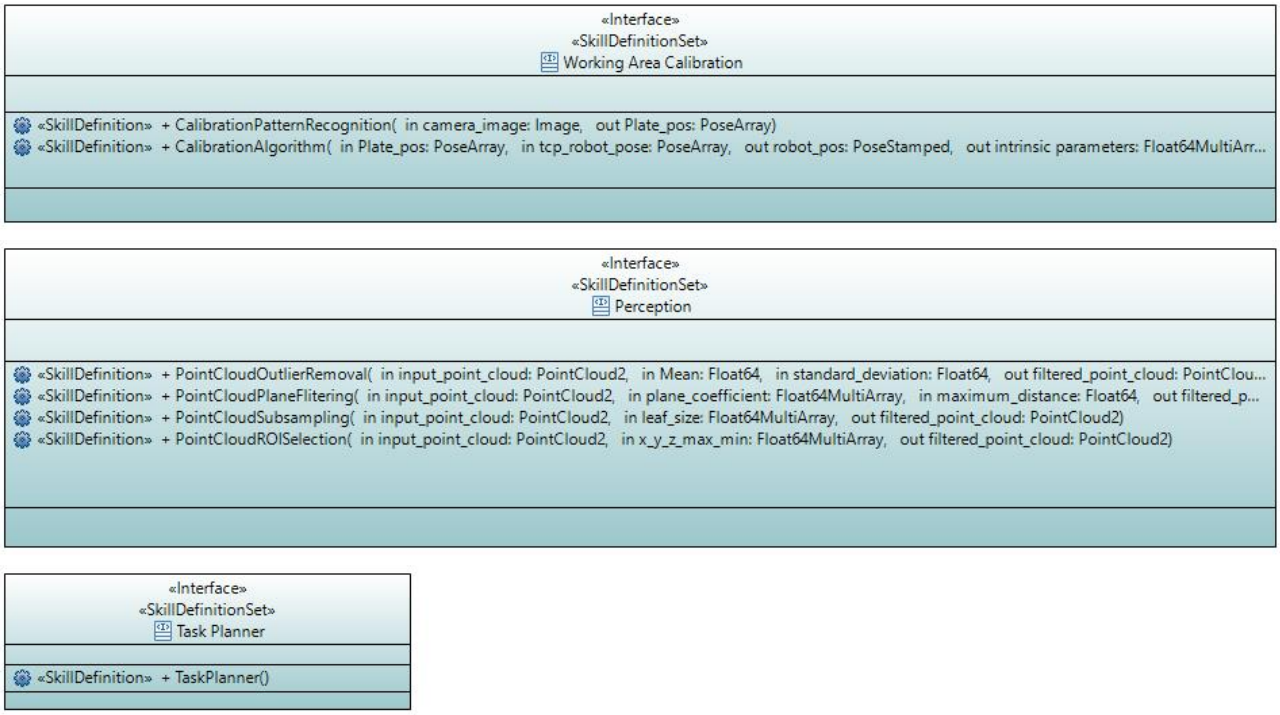
- 3D cameras (sensor_msgs/Image, sensor_msgs/PointCloud2): Ensenso N45, Gocator 3210, Intel RealSense D455, Zivid One+, Zivid Two, Photoneo PhoXi m.
- KEYENCE safety laser scanner (sensor_msgs/PointCloud2, std_msgs/bool)

3.5.3 Skill definition

The skills presented in this document have been defined by the collaboration of the partners: NUTAI, MRNEC and ICPE.

Figure 20 - Skill definition set for ICPE´s use case



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3.5.4 Task Planner

The behavior tree was created by the task planner, in this case, it has been defined in a hierarchical way, following a top bottom approach.

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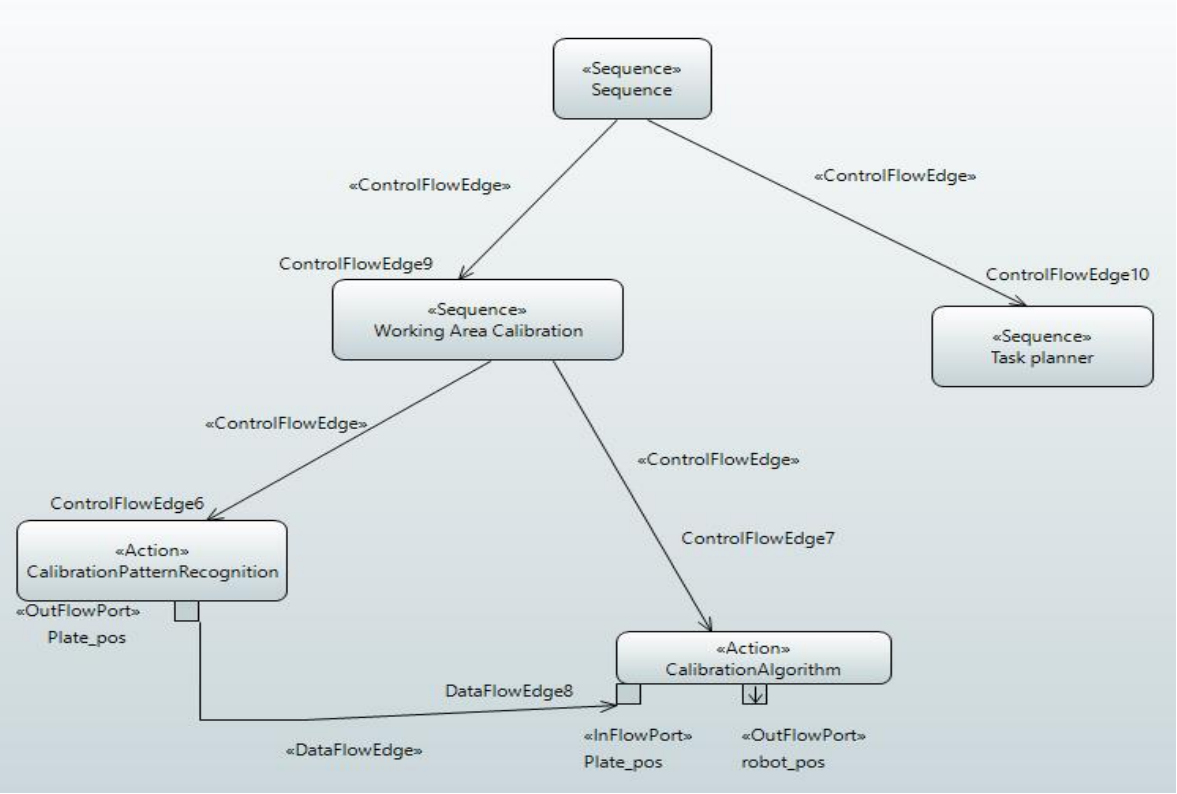
Figure 21 - Behavior tree for ICPE´s use case



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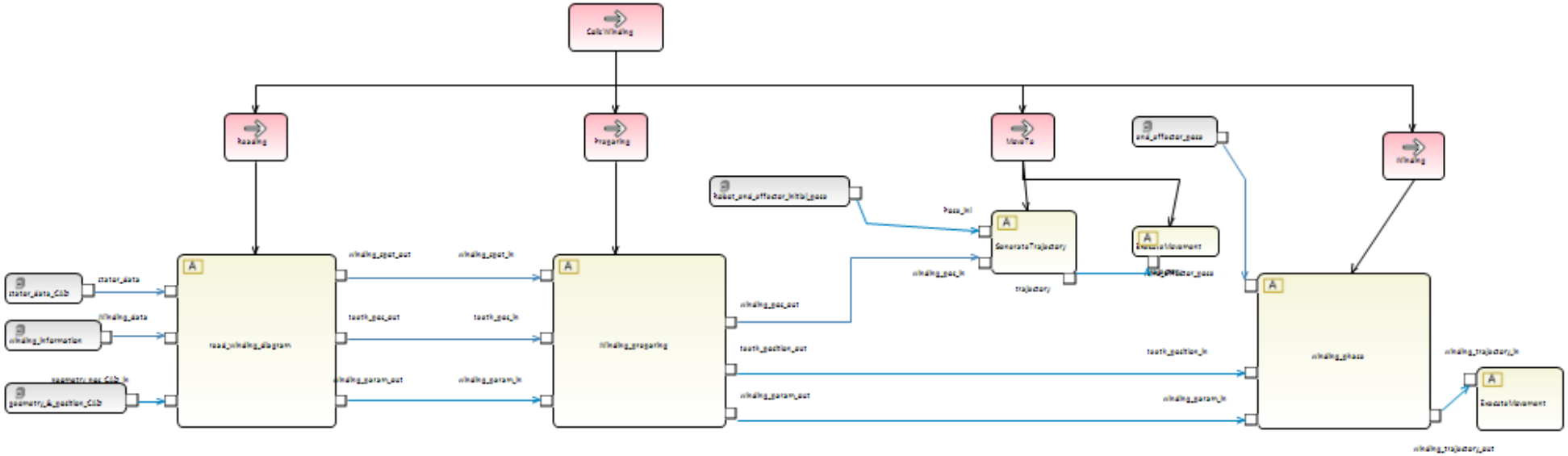

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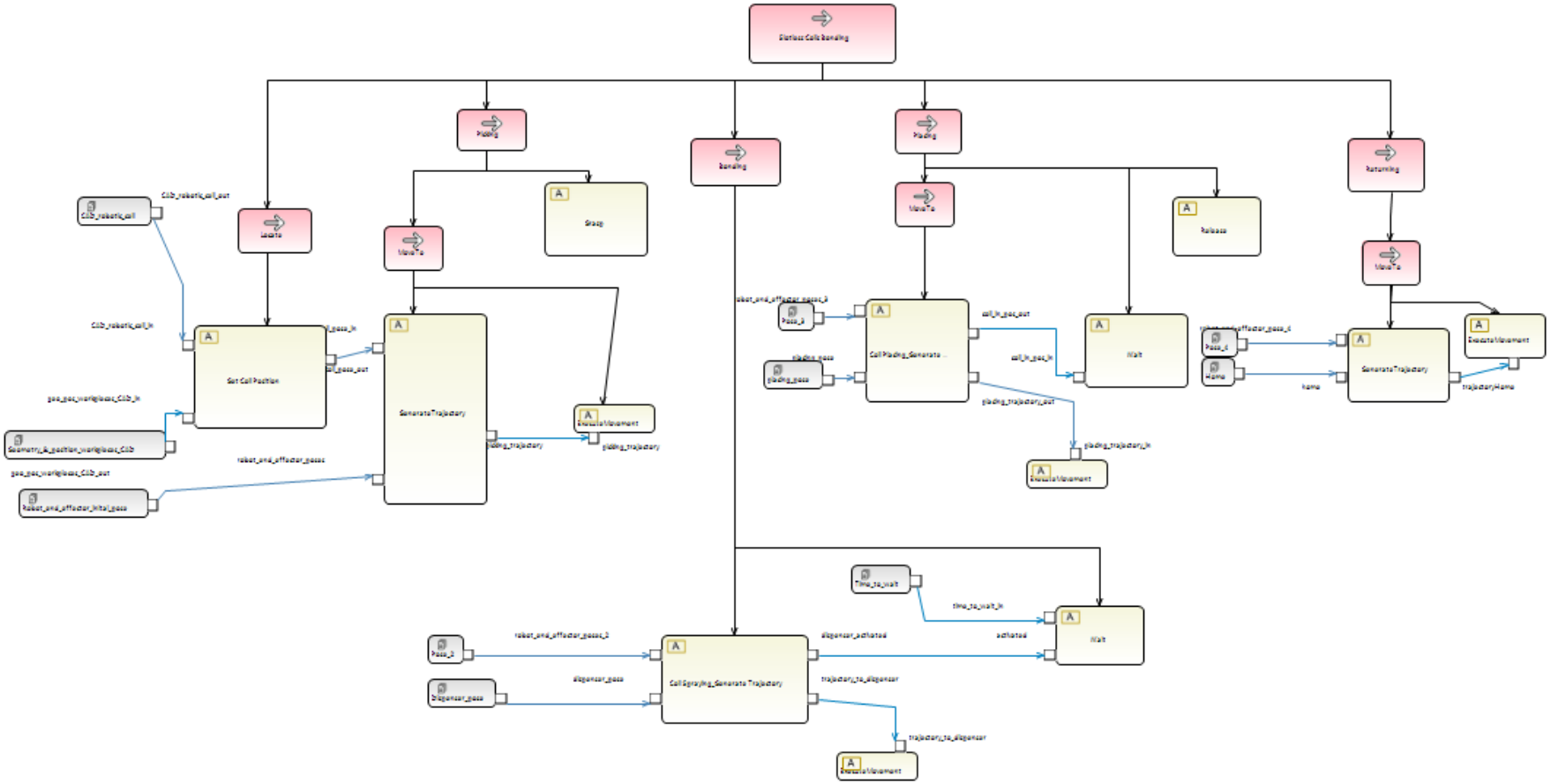

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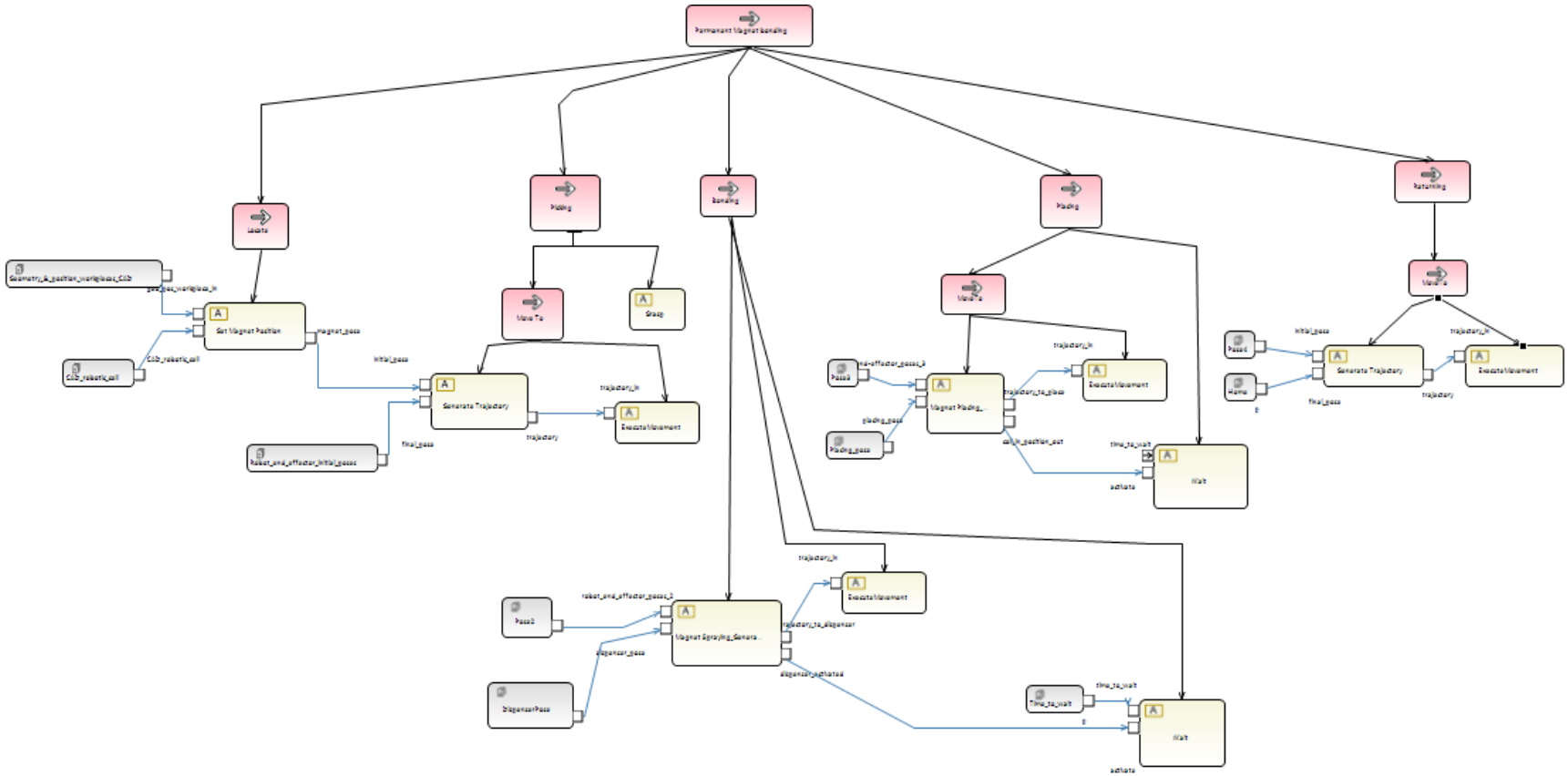

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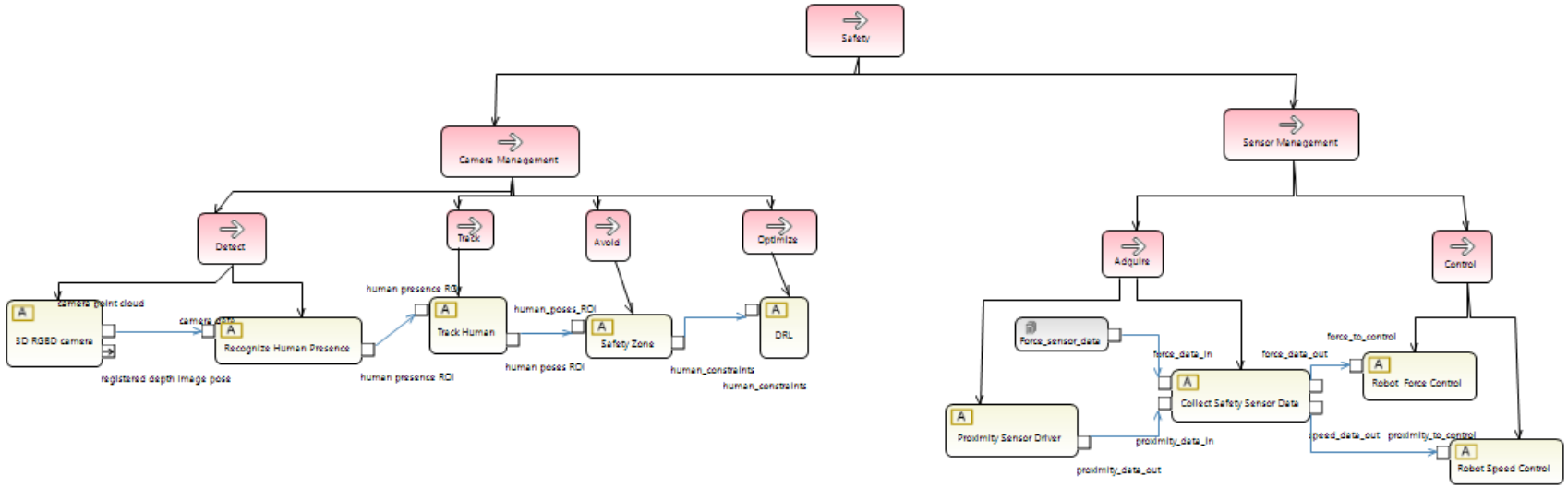

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4 Conclusions

In this document, all the skills and behavior trees necessary for each of the use cases under study have been formally specified.

In this way, the use cases are defined following the necessary guidelines for their correct implementation in the ACROBA architecture developed.

In general, the operating logic and skills have been precisely defined, but there is still some uncertainty when it comes to selecting the necessary HW for each of the use cases.

In order to try to alleviate the effects of this lack of definition, we have instead defined the types of data needed to carry out the different tasks, thus abstracting the HW at the physical level.

Later on in the project, when the real implementation of the use cases is carried out at workshop level, it will be possible to adapt the HW necessary at that precise moment and retouch the definitions of operation made, to date, at a theoretical level.

5 Bibliography

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6 Annexes

There are not related annexes in document format. Papyrus for robotics projects for each use case can be accessed on demand.

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