Training on Collaborative Robots

Introduction

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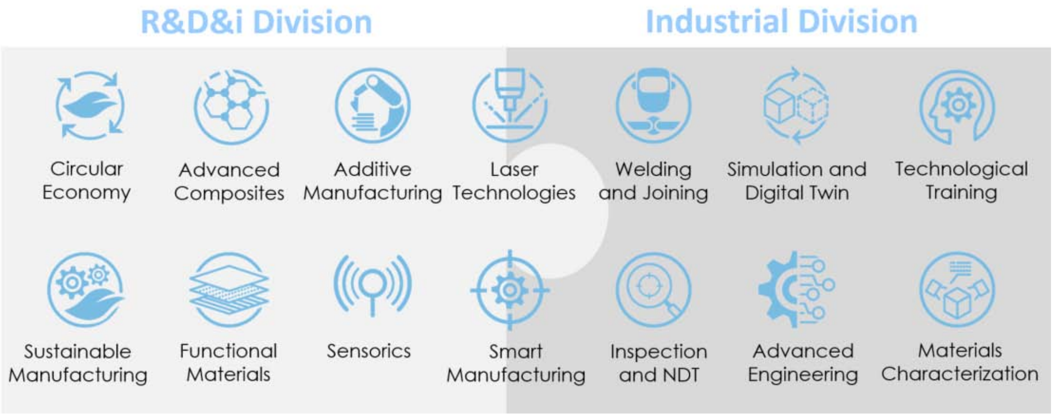
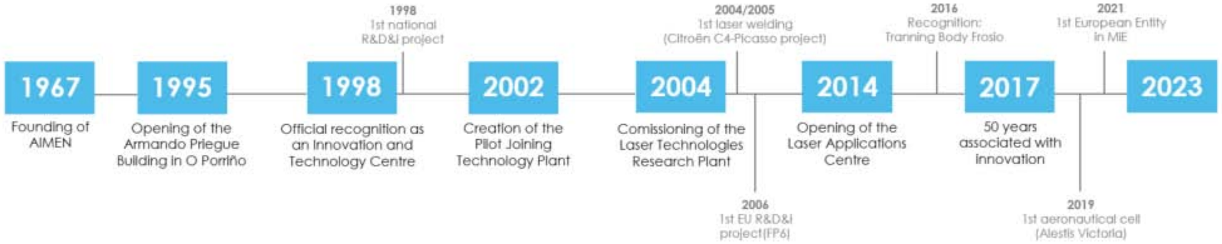
CLOSED-LOOP DIGITAL PIPELINE

These projects have received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

Aimen is a multi-sector innovation and Technology Centre that develops R&D&i activities and provides technological services to the industry fields of Materials, Advanced Manufacturing Processes, Digitalization and Sustainability





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CLOSED-LOOP DIGITAL PIPELINE

MARI4YARD
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Closed-loop digital pipeline for a flexible and modular manufacturing of large components

PENELOPE aims to develop a novel closed-loop digital pipeline. An end-to-end Digital Manufacturing solution, enabling a bidirectional dataflow for seamless integration across the entire manufacturing value chain

DT-FOF-10-2020

Pilot lines for large-part high-precision manufacturing

01

A CLOSED-LOOP DIGITAL PIPELINE

End-to-end digital manufacturing solution.
- Product-centric data management
- Modular and reconfigurable production

02

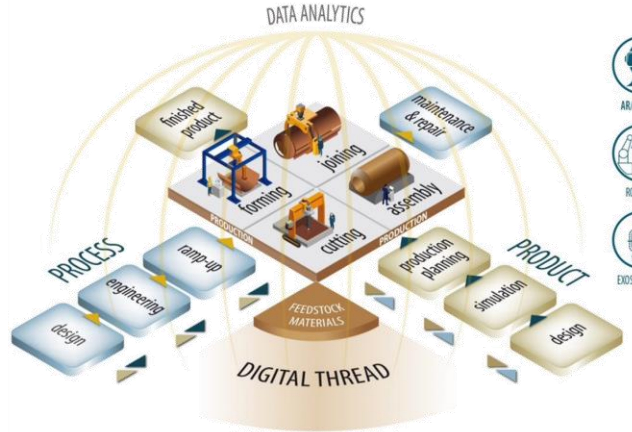
WORKER-CENTRIC SOLUTIONS IN SHARED WORKSPACES

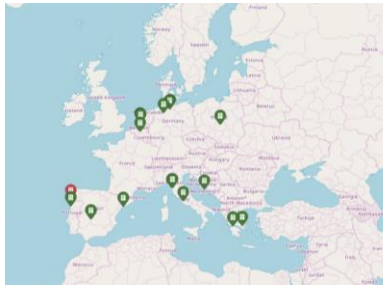
Industry-specific workers' knowledge and skills are preserved.
- Product-centric data management
- Modular and reconfigurable production

03

ZERO-DEFECT MANUFACTURING STRATEGY

AI-powered digital twins.





Mari4_YARD aims to implement a portfolio of worker-centric solutions, by relying on novel collaborative robotics and abiquitous portable solutions, enabling modular, flexible, reconfigurable and usable solutions targeting the execution of key labor-intensive tasks by preserving industry-specific workers' knowledge, skills and biomechanics health status.

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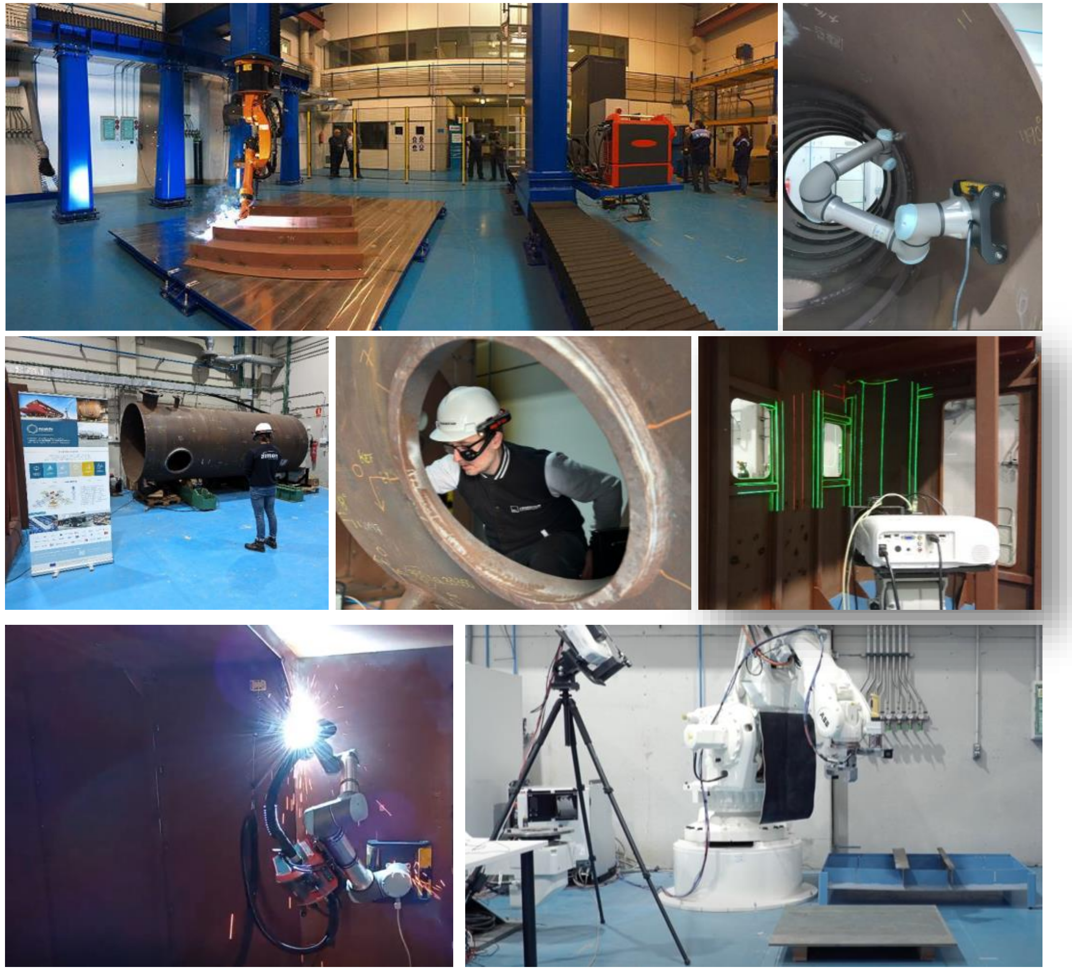
AIMEN DIDACTIC FACTORY

- Training and upskilling capabilities enabling the workforce transition towards Industry 4.0
- A general-purpose testbed for assisting in the industry adoption of digital-centric solutions (INDUSTRY 5.0).



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AGENDA – Day 1 (9 Apr)	Time 9:00 – 16:00
Reception & Welcome	9:00 – 9:15
Introduction to the training	9:15 – 9:30
Industrial robots programming ❖ Robot System; ❖ Robot movement within a 3D space; Examples & Exercises	9:30 – 10:30
Coffee Break	10:30 – 11:00
❖ Moving a robot; ❖ Robot Programming Examples & Exercises	11:00 – 12:00
Welding with collaborative robots ❖ Welding system: Cobot, Welding equipment	12:00 – 13:30
Lunch	13:30 – 14:30
❖ Welding application (WelderBot) Examples & Exercises	14:30 -16:00
End of the Day	16:00

AGENDA – Day 2 (10 Apr)	Time 9:00 – 13:00
Reception & Welcome	9:00 – 9:15
Introduction Collaborative Robotics and Safety. ➢ Understanding and practical insights into collab orative and embodied robotics for industrial ap plications ➢ Human tracking, Speed and Sperate Monitoring	9:15 – 9:45
Introduction to HandGuiding applications. ➢ Hardware & Software ➢ Technology deployment .Development ➢ Applications	9:45 – 10:10
Introduction to Cutting application with Cobots	10:10 -10:30
Coffee Break	10:30 – 11:00
Practical Demonstrations	11:00 – 13:00
End of the Day	13:00

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Industrial robots Programming

Isidro Fernández Iglesias
O Porriño, 9th April 2024

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TECHNOLOGY CENTRE

Contents

These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

1-Robot system: Industrial robot definition

An industrial robot is a programmable manipulator with at least 3 controlled axes, able to perform a lot of different tasks depending on the tool attached to the robot flange. It is composed by a Mechanical arm and a Control system.

These are industrial robots

This is NOT an industrial robot

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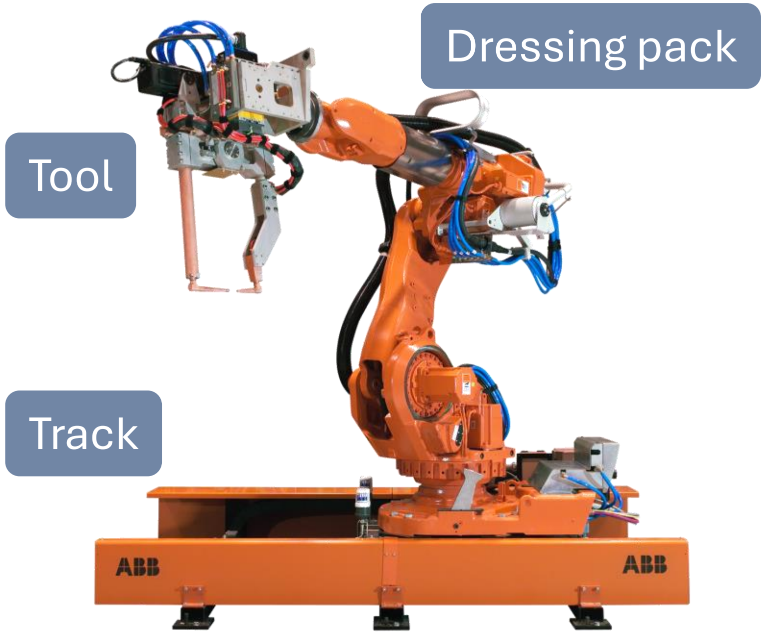
1-Robot system: Industrial robot components

A “naked” industrial robot is composed by a manipulator (mechanical arm) a control cabinet, and a programming device.

“Naked” robot



Robot and other accessories

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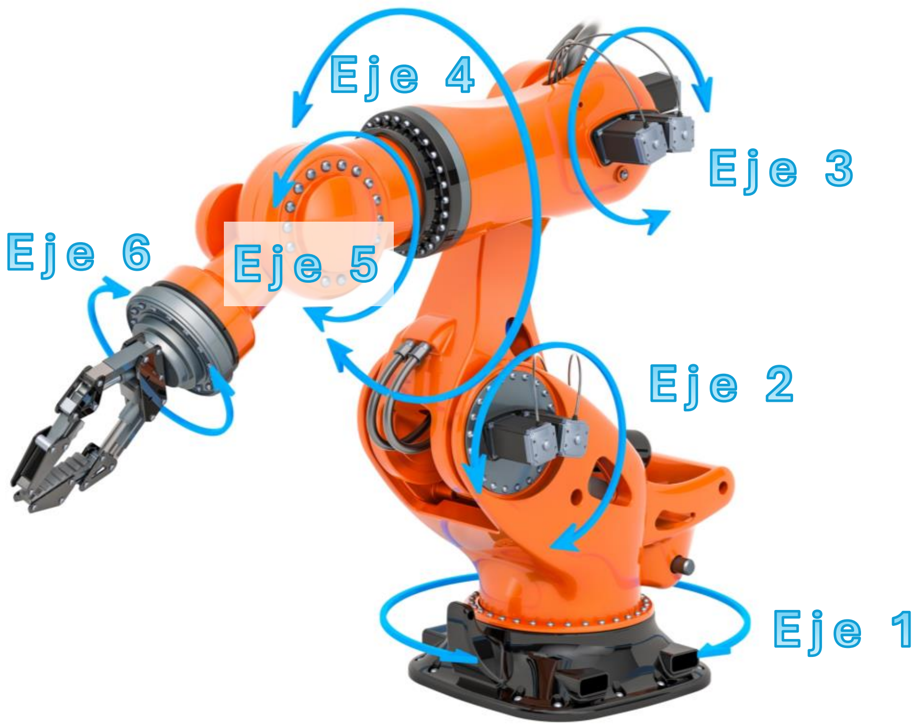
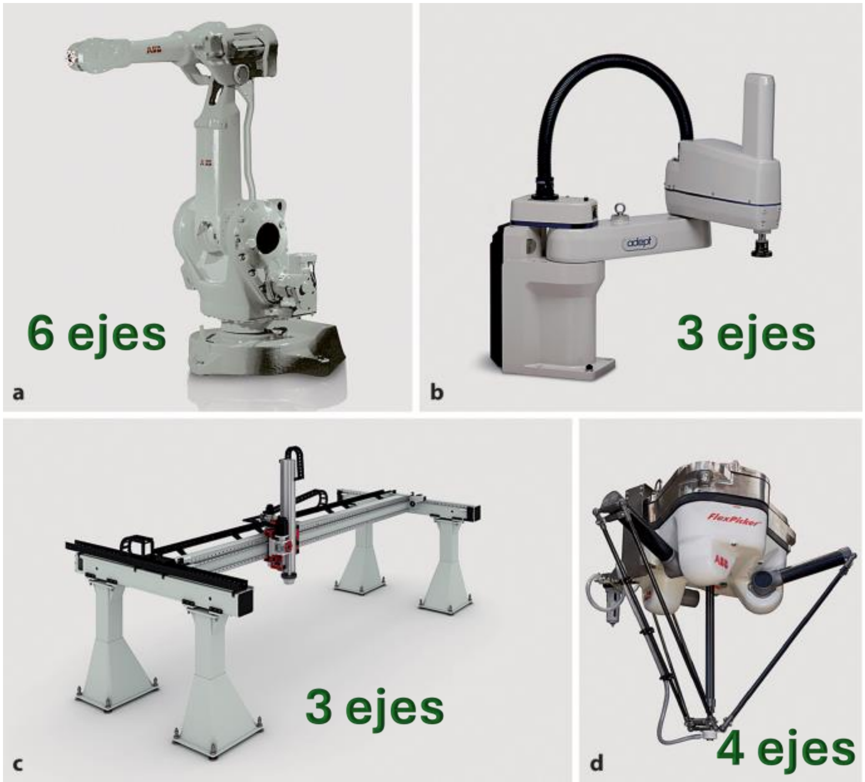
1-Robot system : Robot Arm configuration

The most common robot arm configuration is the one similar to the human body arm, usually composed by 6 rotatory axes, driven by electric motors in each axis. This is the most versatile configuration





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1-Robot system: Industrial robot applications

An industrial robot can be used to perform almost any productive process, quickly, precisely and with high accuracy. Robot application is determined by the tool attached to the robot tool flange.

Arc welding

Spot welding

Manipulation

Gluing dispensing

Drilling-Milling

Laser cutting

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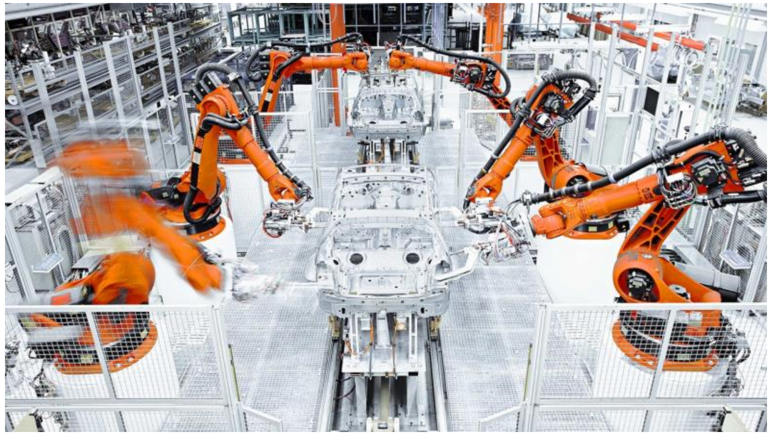
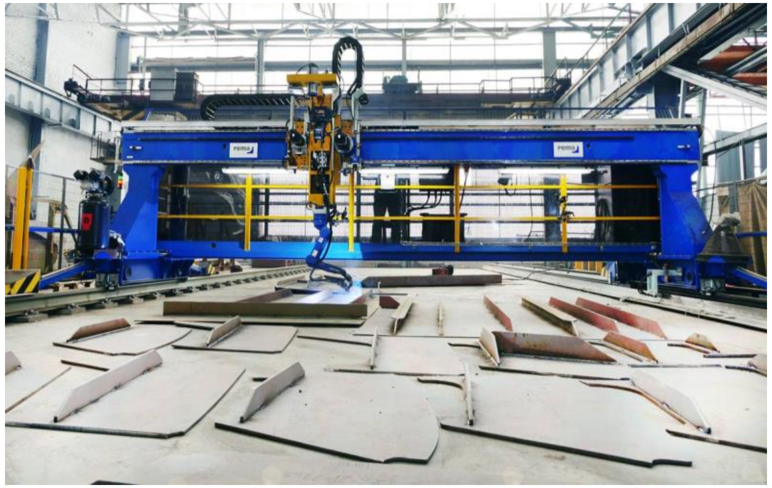
1-Robot system: Processes that can be robotized

An industrial robot is very efficient in its performance, doing repetitive tasks once and again, like in massive production systems where just one type of product (or a few of them) is manufactured repeatedly.
Automotive is a good example of this, where hundreds of robots work in BodyInWhite and Pressing lines.



Nowadays, new trend is to use industrial robots in unitary or very short-units production systems. To get this goal new technologies, like artificial vision, and applications are being developed to avoid high skilled robot operators.



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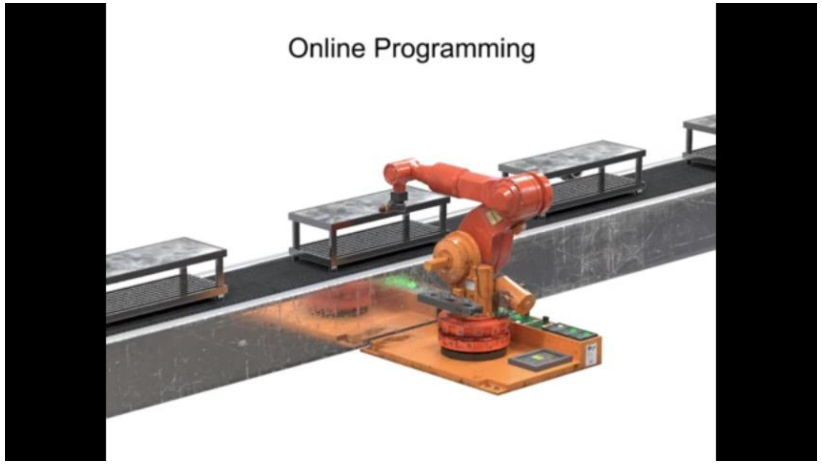
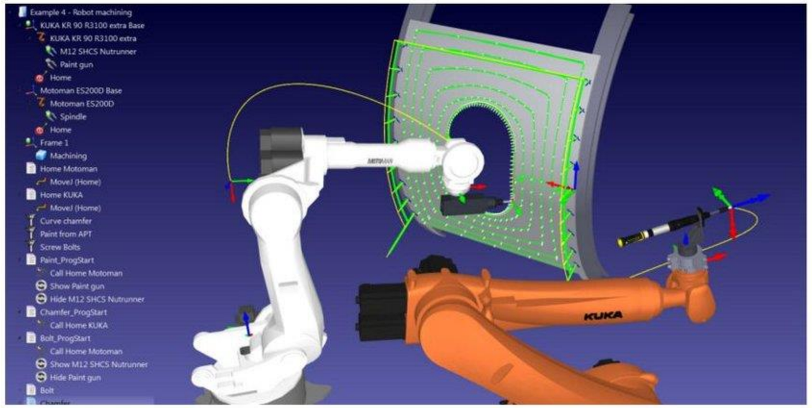
1-Robot system: How to program a robot

If we want an industrial robot to perform a process, we have to teach it the robot movements. To do that there are several possibilities:

1. Using the robot teach unit to teach robot positions, moving the robot manually.
2. Using a robot simulator software to get the robot positions.
3. Using a part localization system (artificial vision) to improve robot position accuracy from predefined positions.
4. Using other guide systems.





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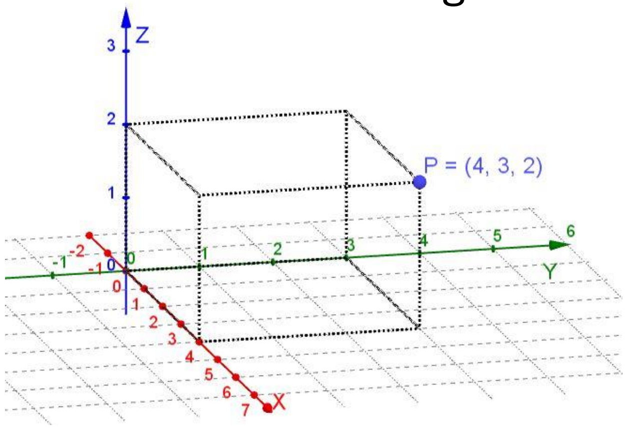
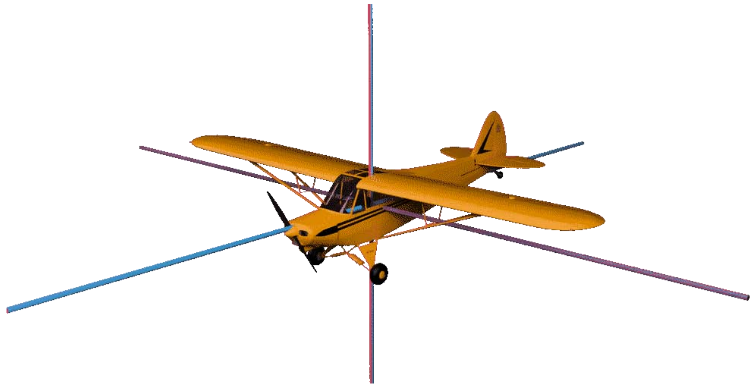
2-Robot movement within a 3D space

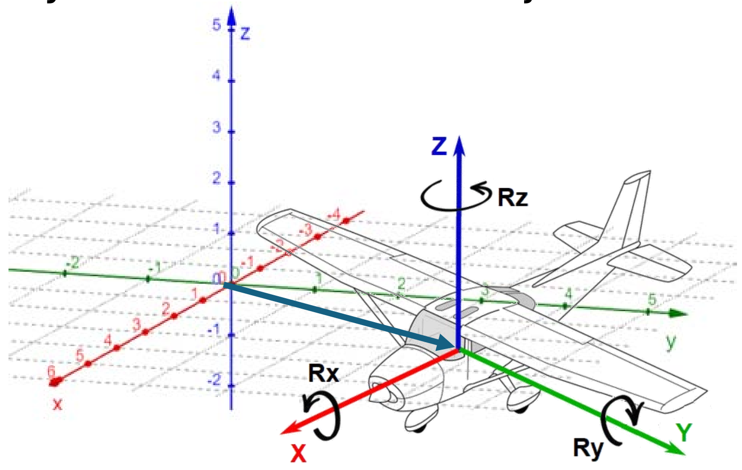
To move an object in a 3D space (cartesian=XYZ) we need references to know how much and in what direction we want the object to move.
To do that, cartesian coordinates system is used: One origin and 3 XYZ perpendicular directions.
To know a "point" position in a 3D space, we need to know its (x,y,z) coordinates regarding to a reference system, previously defined in any place we have decided.
To know an "object" position in a 3D space, we need to know its (x,y,z) position and how much it is rotated (Rx,Ry,Rz) regarding to a reference system. We use an auxiliary reference system linked to the object which moves with it to get calculous easily.



Point P position defined in a cartesian system XYZ



Auxiliary reference system linked to an object



Position and orientation of an object defined in a cartesian system XYZ

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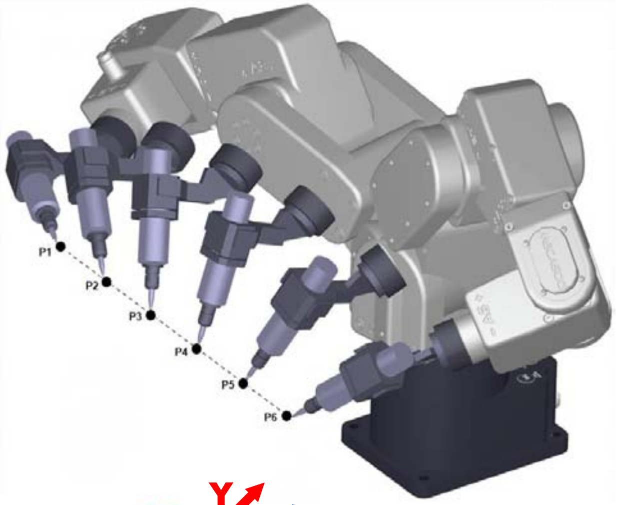
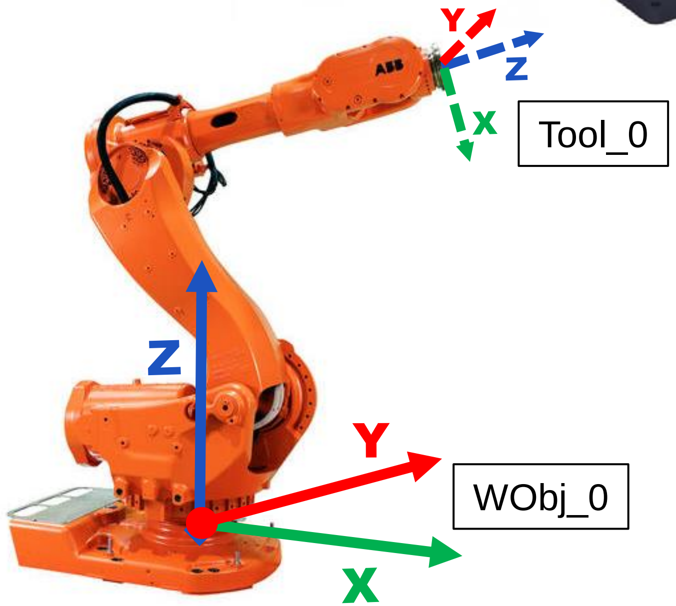
2-Robot movement within a 3D space



1. The robot's tool is an "object" within a 3D space, and we want the robot to move it along different positions, with or with not the same orientation, to define and program a movement trajectory of that tool.



2. A new delivered robot comes without any tool attached to its robot tool flange (axis 6).
3. In that conditions, a reference system XYZ is defined on robot's base, named "Base" system, or "WorkObject_0"...etc.
4. On the robot tool flange is defined an auxiliary reference system named "Tool_0".

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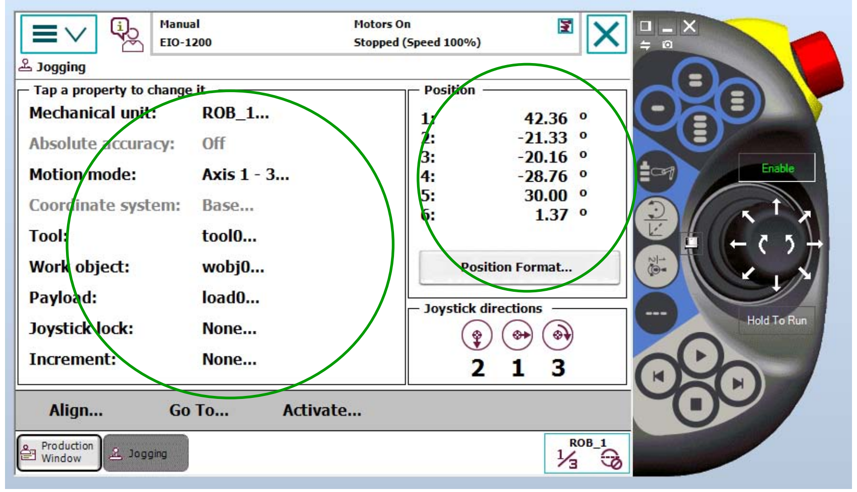
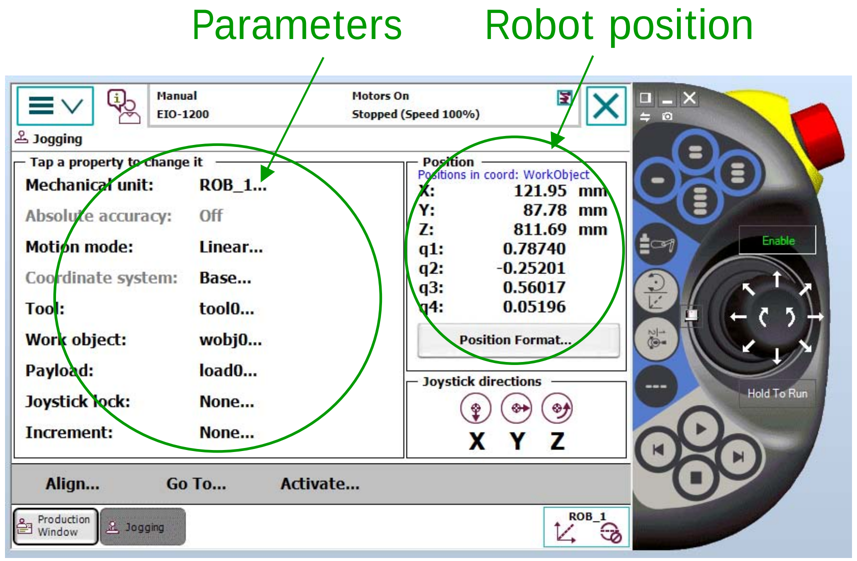
2-Robot movement within a 3D space

If we want to know the position and orientation of any robot tool fitted to it, we have to read these information on the teach unit, in a dedicated window.

In this window we can read the information of robot position in two formats:

- Angular format: it gives us the position of every single robot axis in degrees.
- Cartesian format: it gives us the (xyz) position and the (RxRyRz) orientation of any tool fitted to the robot regarding the robot base system reference (wobj0).





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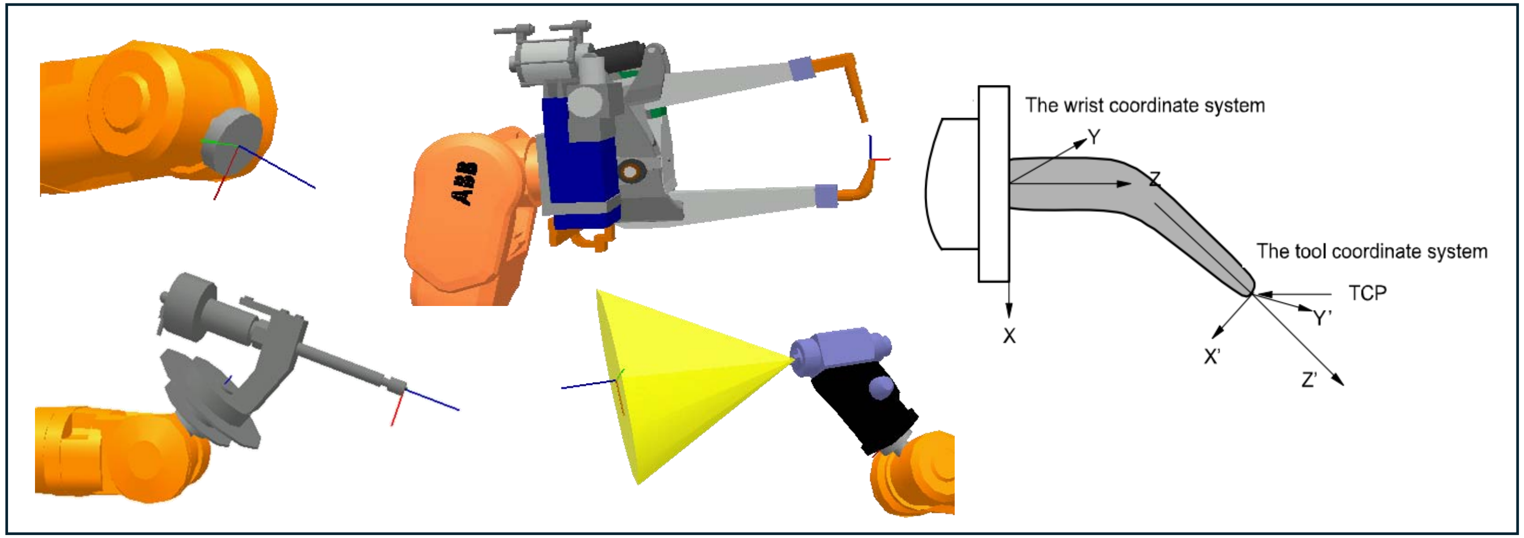
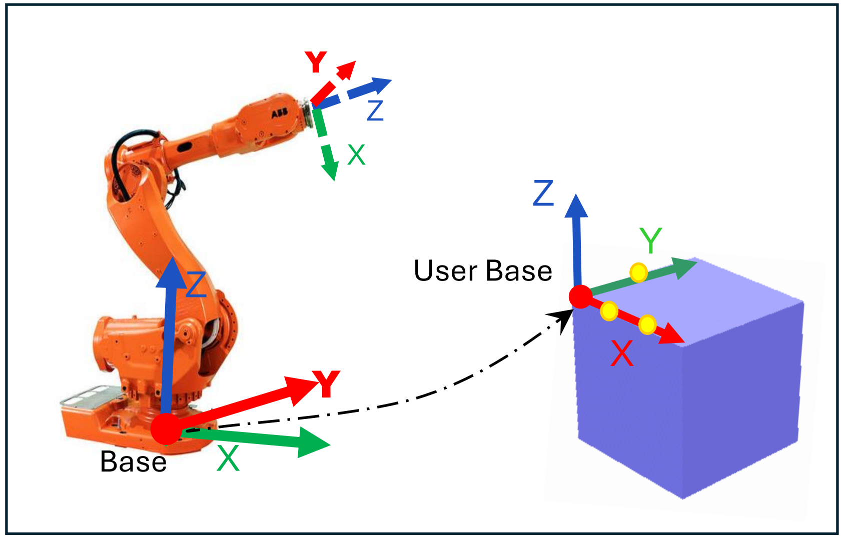
2-Robot movement within a 3D space

If we want to know position and orientation of any tool fitted to the robot, we have to define an auxiliar reference system linked to the real tool onto a particular point named “TCP=Tool Center Point”. With this information the robot is able to calculate the position and orientation of this point on the tool and can be read by an operator from the dedicated window on the teach unit.
We can also define a reference system additionally to the base reference system (Wobj0) in any place in 3D space to make easy some robot programming tasks, or if it is needed to coordinate the robot with other devices (other robots, vision system....).





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3-Moving a robot: How to move

A robot can be easily moved in two exclusive different ways. Within each of these two possibilities there are two options to execute the movements, whether to execute a tool translational movement, or a tool orientation movement:

1. Using whether a dedicated movement buttons on the teach unit, or a joystick: This option allows the operator to move the robot tool from one point in space to other point (XYZ RxRyRz) to teach and save that position in robot controller. Operator works in "MANUAL" mode with the teach unit besides the robot.

2. Executing a movement instruction inside a robot program with positions (XYZ RxRyRz) previously teached. Operator executes the program whether in reduced speed mode (MANUAL), whether in fast speed mode (AUTOMATIC).

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3-Moving a robot: Robot movement types

A robot can move its 6 axes independently.

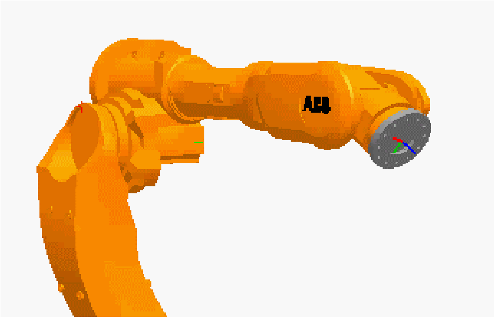
Axis_1

Axis_2

Axis_3

Axis_4

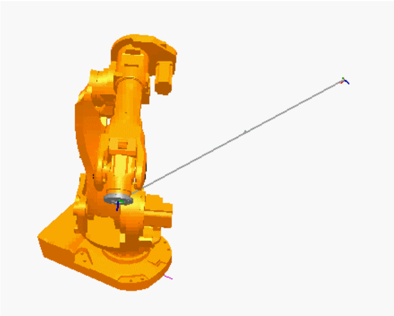
Axis_5



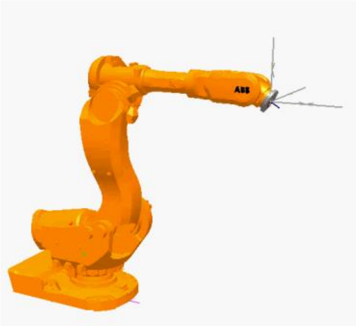
Axis_6

A robot can also move describing linear or reorientation movements, moving its 6 axes at the same time in a combined way.

Tool reorientation



Linear movement



Linear movement parallel to robot base reference

Linear movement parallel to robot tool reference

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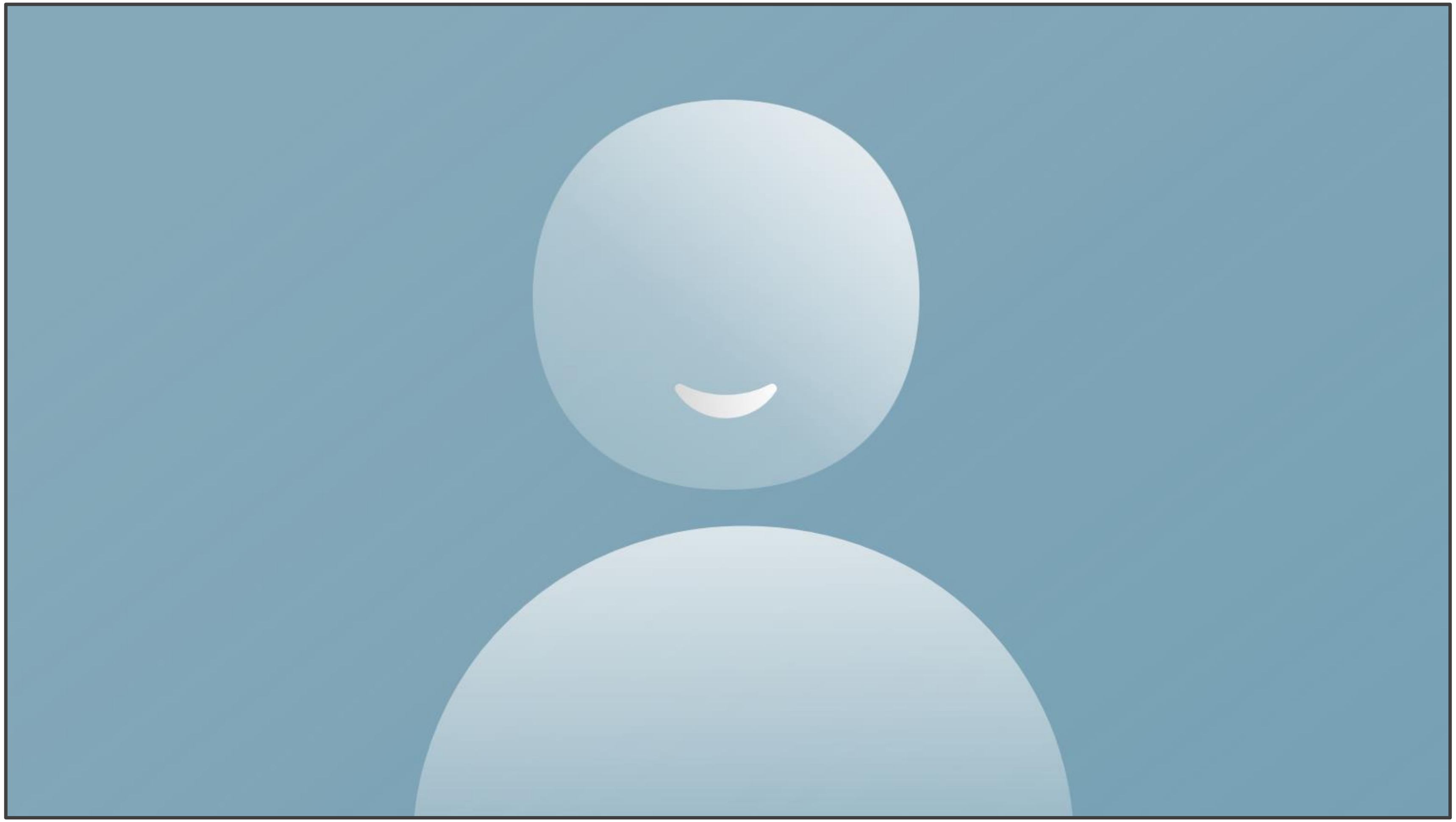
3-Moving a robot: Practice



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COFFEE BREAK

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4-Robot programming: Robot program structure

A robot is able to perform a process with a fitted tool (manipulation, welding....etc) by mean of a group of instructions/commands saved on its memory as code lines, which will be executed one by one to get the robot to perform the movements and other actions the operator had previously teached, and in this way repeat the process once and again infinitely.

Code lines can be whether **movement instructions**, letting the robot moving to a specific position, whether **digital signals reading/writing instructions** to handle signals, or **control instructions** to execute the robot program in one way or other depending on some conditions.

These instructions grouped and saved are named **robot program**, and they are saved in robot's memory in order the robot be able to execute them. The robot program can be saved also in a "text" file, and it can be downloaded or uploaded from robot to a Pc or vice versa by mean of an external memory USB type.

However, a robot program is not just composed by code lines (instructions), but also by a set of data we should define. These data are used inside the program instructions: position data, numeric data, coordinate system data....etc.

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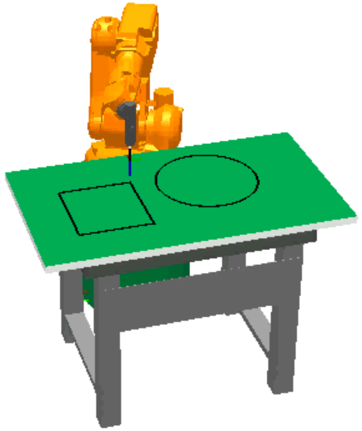
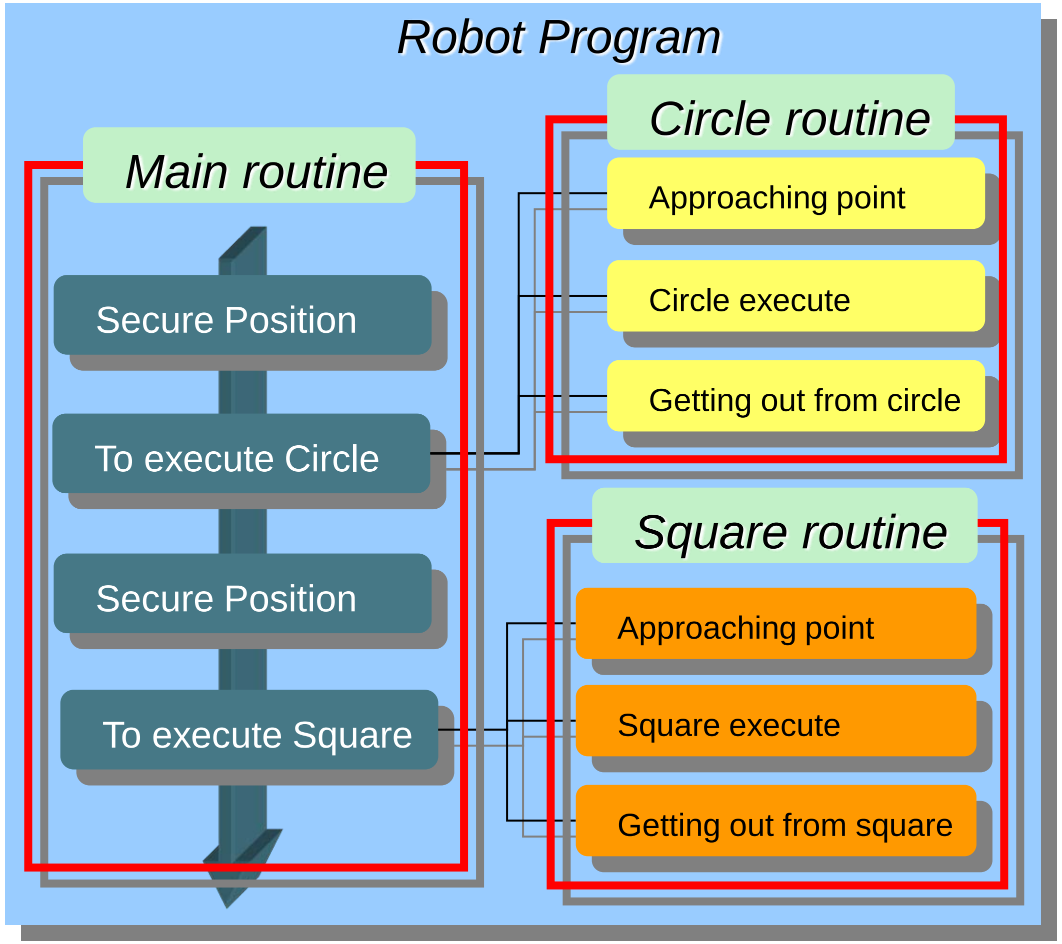
4-Robot programming: Robot program structure

In a robot program to be more readable and tidy up, instructions are grouped in routines (subprograms) to reuse them in different areas through a complete robot process (e.g., instructions code to open or close a gripper fitted to the robot).

All the routines have to have a name different from others.

There is always a routine from where the robot process is starting and from where other routines can be executed.





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4-Robot programming: How to manage program execution

The robot will be able to execute a group of instructions in case these instructions with the associated data have been programmed previously. To do that we can open the “**programing**” window in the robot teach unit.

There is an indicator in the programming window to point out and highlight the next instruction is going to be executed by the robot when the “**Play/Start**” button will be pressed. This indicator is named **Program Pointer**.

To execute a robot program, we have to place this program pointer onto the first routine instruction we want to execute. Afterwards, we will push the Play button to execute the whole program, or just push the “**Step Forward**” button to execute just one instruction each time. We can move the program pointer inside the selected routine to other instruction instead of the first, to execute it whithout executing the previous ones.

We can also modify the overall robot speed when it is moving executing a program, changing the field **Speed Override**. It is a value between **0% and 100%** of the programmed speed.

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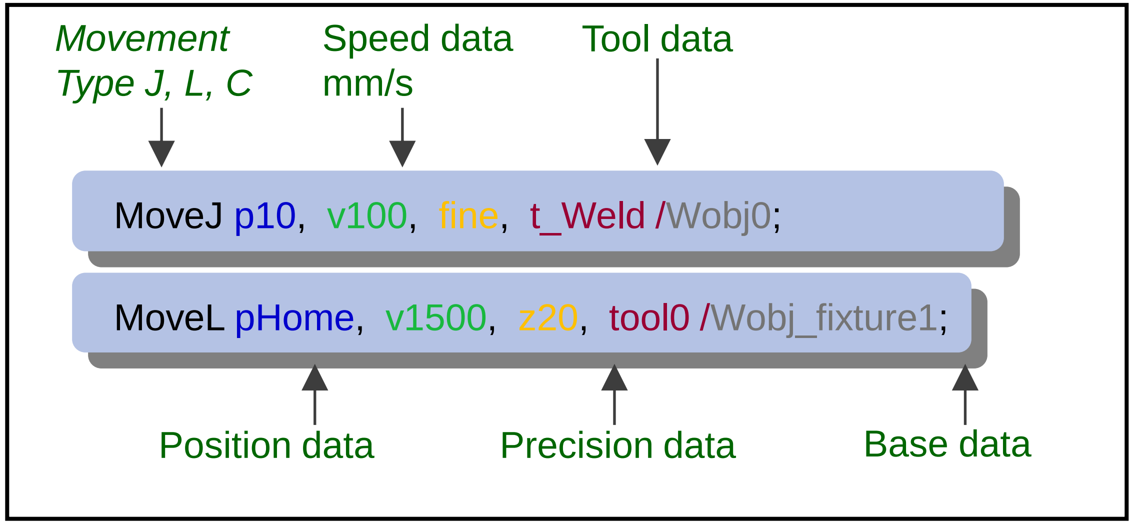
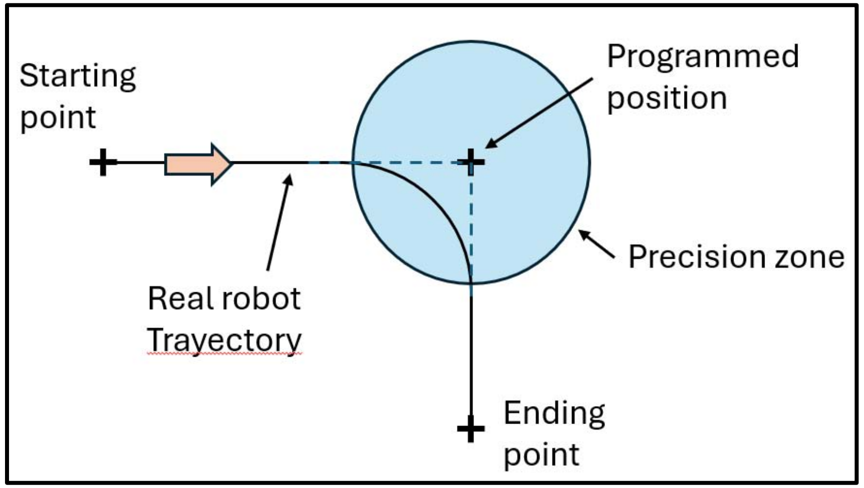
4-Robot programming: Movement instruction

A robot movement instruction is able to move the robot from the current robot position to the position previously teached inside the position data linked to the instruction.

The ABB robot movement instruction is composed by the next fields (parameters):





The precision parameter is responsible for robot trajectory precision when instruction is executed. This parameter can perform a trim down robot trajectory of a defined radius while program executing, or just execute the exact trajectory.

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4-Robot programming: Robot program example

```
PROC main()
    Reset do_DrawingTriangle;
    Reset do_DrawingSquare;
    Reset do_WaitingToDraw;
    MoveJ pHome,v150,fine,tool0\WObj:=wobj0;
    !
    !Starting to draw the Triangle
    Set do_WaitingToDraw;
    WaitDI di_Start,1;
    Reset do_WaitingToDraw;
    WaitDI di_Start,0;
    MoveJ pHome,v150,fine,tool0\WObj:=wobj0;
    Set do_DrawingTriangle;
    DrawTriangle;
    Reset do_DrawingTriangle;
    !
    !Starting to draw the Square
    Set do_WaitingToDraw;
    WaitDI di_Start,1;
    Reset do_WaitingToDraw;
    WaitDI di_Start,0;
    MoveJ pHome,v150,fine,tool0\WObj:=wobj0;
    Set do_DrawingSquare;
    DrawSquare;
    Reset do_DrawingSquare;
ENDPROC
```

```
PROC DrawTriangle()
    MoveL Offs(p10_Triangle,0,0,200),v100,fine,t_Tip\WObj:=w_Fixture;
    MoveL p10_Triangle,v100,fine,t_Tip\WObj:=w_Fixture;
    MoveL p20_Triangle,v100,fine,t_Tip\WObj:=w_Fixture;
    MoveL p30_Triangle,v100,fine,t_Tip\WObj:=w_Fixture;
    MoveL p10_Triangle,v100,fine,t_Tip\WObj:=w_Fixture;
ENDPROC
```

```
PROC DrawSquare()
    MoveL Offs(p10_Square,0,0,200),v100,fine,t_Tip\WObj:=w_Fixture;
    MoveL p10_Square,v100,fine,t_Tip\WObj:=w_Fixture;
    MoveL p20_Square,v100,fine,t_Tip\WObj:=w_Fixture;
    MoveL p30_Square,v100,fine,t_Tip\WObj:=w_Fixture;
    MoveL p40_Square,v100,fine,t_Tip\WObj:=w_Fixture;
    MoveL p10_Square,v100,fine,t_Tip\WObj:=w_Fixture;
ENDPROC
```

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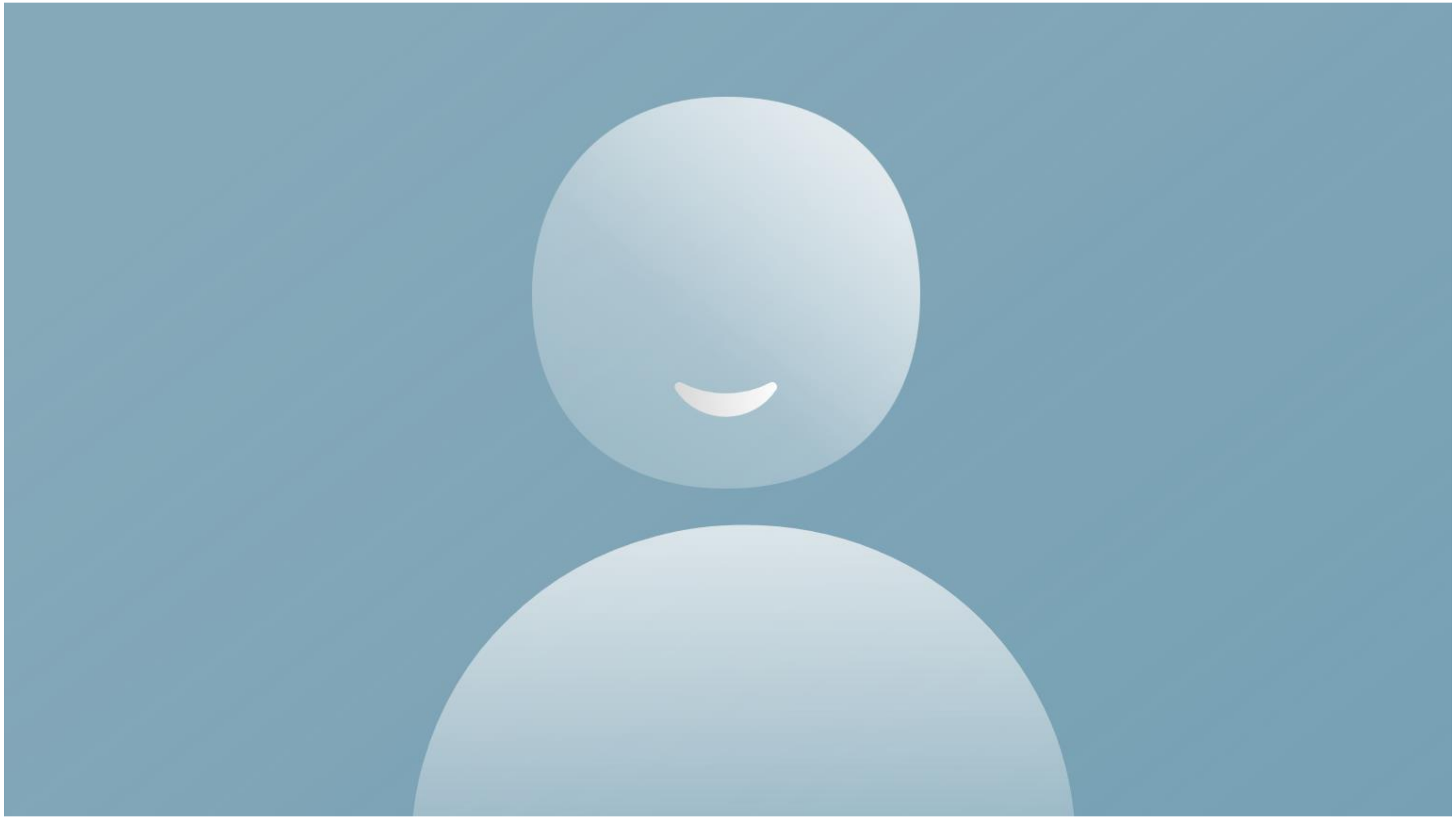
4-Robot programming: Practice



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Collaborative Robotics Tools

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Collaborative & embodied robotics

Technological advances towards human centric industries

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Instructor: Jawad, Isidro, Claudio, Afra
10th April, 2024

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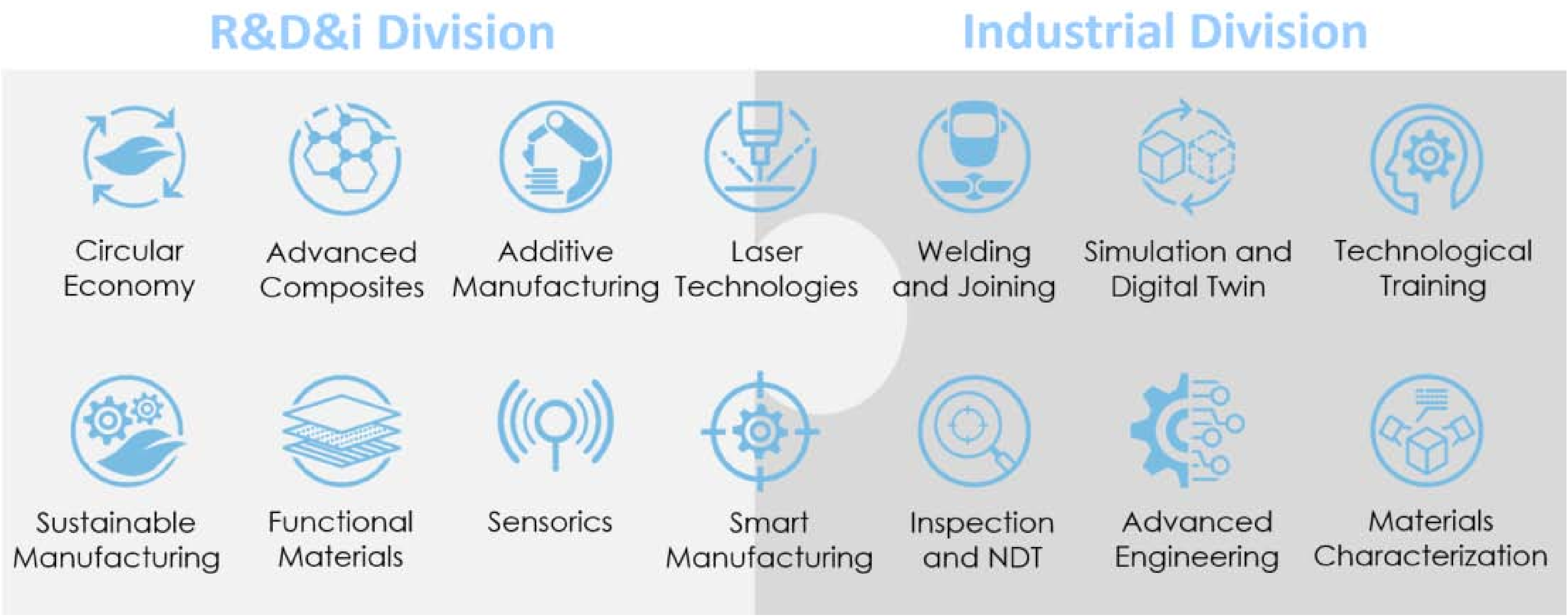
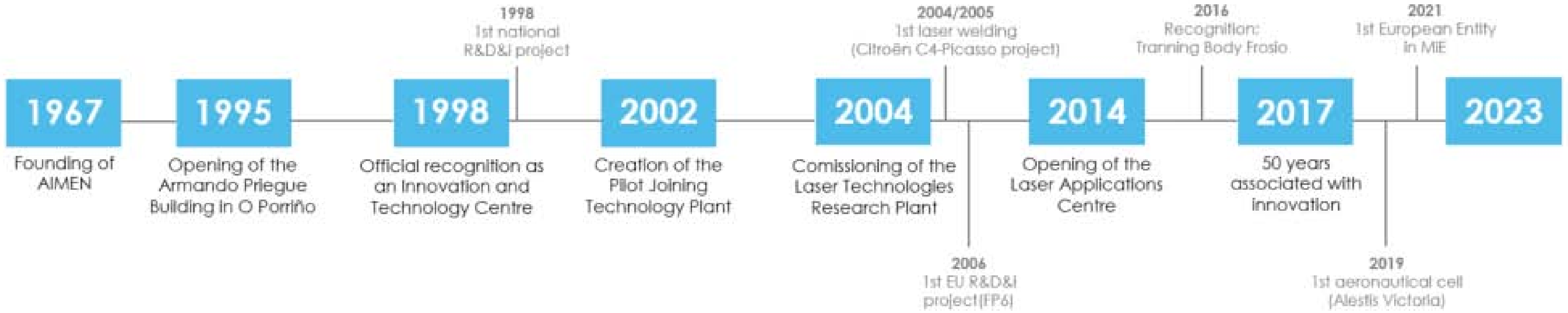
Aimen is a multi-sector innovation and Technology Centre that develops R&D&i activities and provides technological services to the industry fields of Materials, Advanced Manufacturing Processes, Digitalization and Sustainability



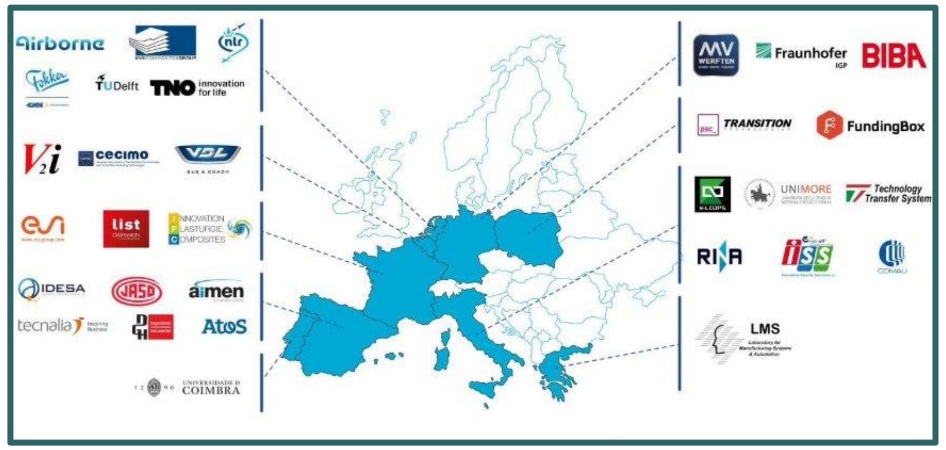


These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

PeneloPe
CLOSED-LOOP DIGITAL PIPELINE

MARI4YARD
MARI4ALLIANCE

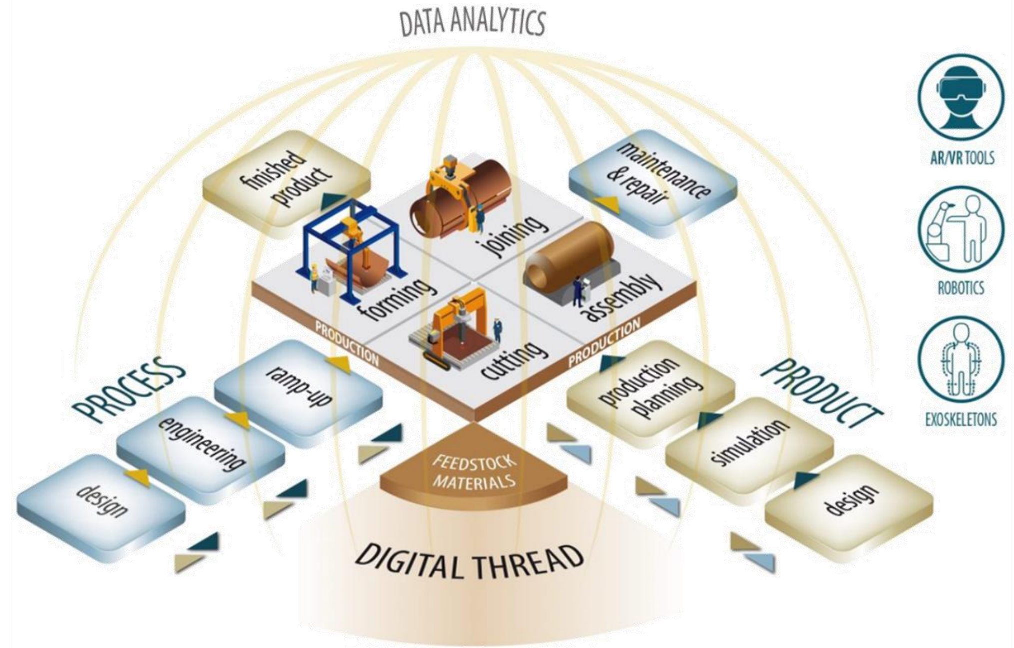
Closed-loop digital pipeline for a flexible and modular manufacturing of large components



PENELOPE aims to develop a novel closed-loop digital pipeline. An end-to-end Digital Manufacturing solution, enabling a bidirectional dataflow for seamless integration across the entire manufacturing value chain

DT-FOF-10-2020

Pilot lines for large-part high-precision manufacturing



01

A CLOSED-LOOP DIGITAL PIPELINE

End-to-end digital manufacturing solution.
- Product-centric data management
- Modular and reconfigurable production

02

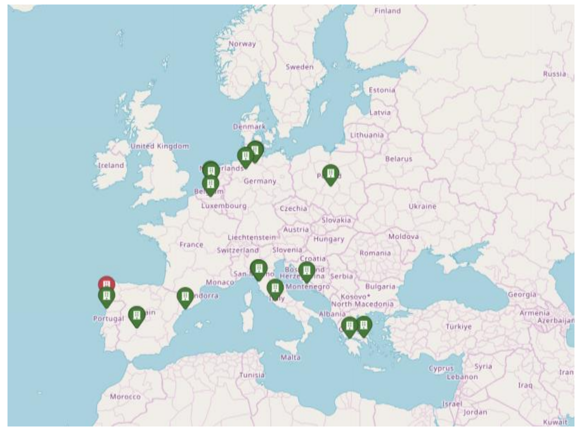
WORKER-CENTRIC SOLUTIONS IN SHARED WORKSPACES

Industry-specific workers' knowledge and skills are preserved.
- Product-centric data management
- Modular and reconfigurable production

03

ZERO-DEFECT MANUFACTURING STRATEGY

AI-powered digital twins.



Mari4_YARD aims to implement a portfolio of worker-centric solutions, by relying on novel collaborative robotics and abiquitous portable solutions, enabling modular, flexible, reconfigurable and usable solutions targeting the execution of key labor-intensive tasks by preserving industry-specific workers' knowledge, skills and biomechanics health status.

These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

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CLOSED-LOOP DIGITAL PIPELINE

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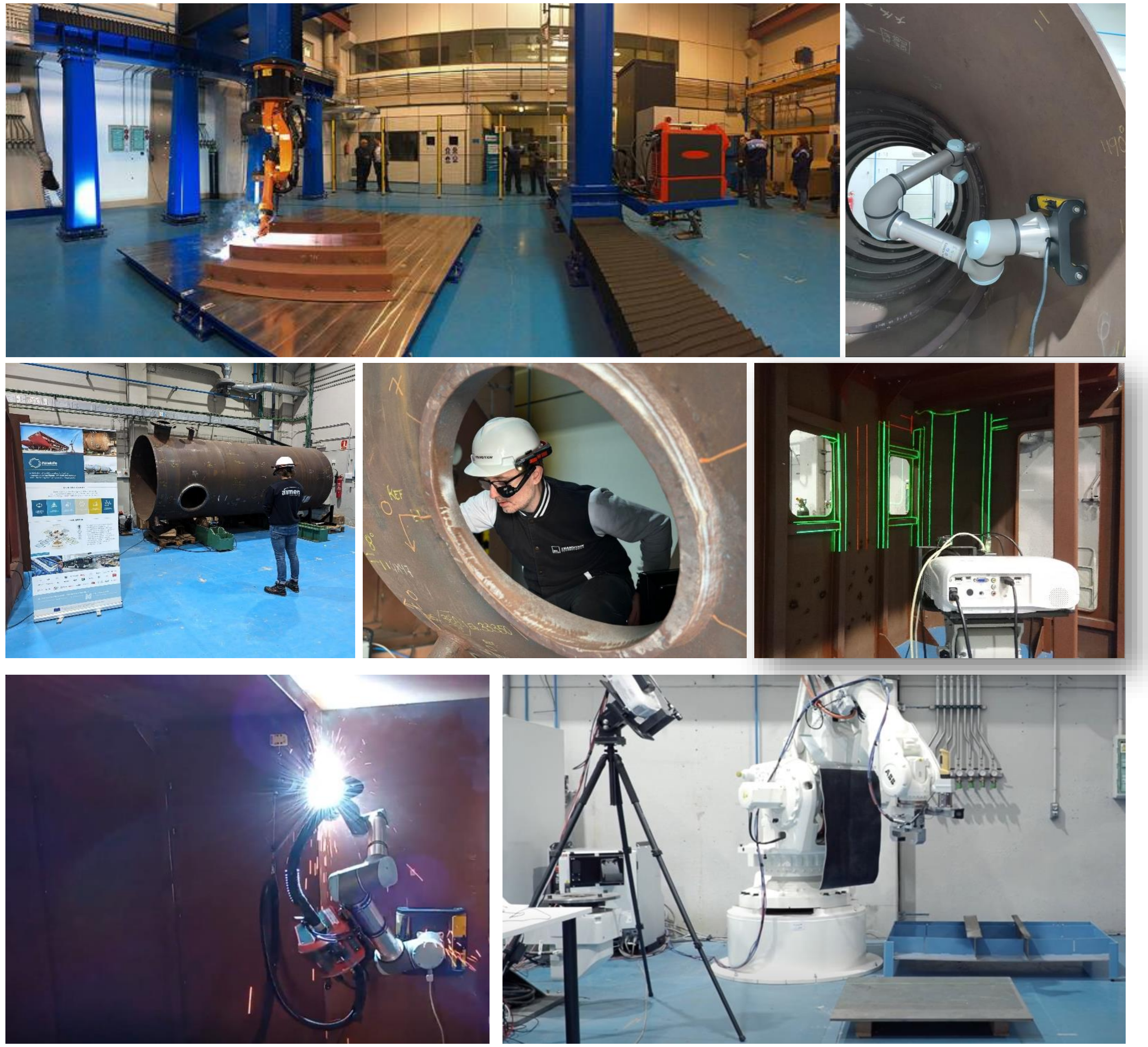
AIMEN DIDACTIC FACTORY

- Training and upskilling capabilities enabling the workforce transition towards Industry 4.0
- A general-purpose testbed for assisting in the industry adoption of digital-centric solutions (INDUSTRY 5.0).



These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

AGENDA – Day 1 (9 Apr)	Time 9:00 – 16:00
Reception & Welcome	9:00 – 9:15
Introduction to the training	9:15 – 9:30
Industrial robots programming ❖ Robot System; ❖ Robot movement within a 3D space; Examples & Exercises	9:30 – 10:30
Coffee Break	10:30 – 11:00
❖ Moving a robot; ❖ Robot Programming Examples & Exercises	11:00 – 12:00
Welding with collaborative robots ❖ Welding system: Cobot, Welding equipment	12:00 – 13:30
Lunch	13:30 – 14:30
❖ Welding application (WelderBot) Examples & Exercises	14:30 -16:00
End of the Day	16:00

AGENDA – Day 2 (10 Apr)	Time 9:00 – 13:00
Reception & Welcome	9:00 – 9:15
Introduction Collaborative Robotics and Safety. ➢ Understanding and practical insights into collabo rative and embodied robotics for industrial applic ations ➢ Human tracking, Speed and Sperate Monitoring	9:15 – 9:45
Introduction to HandGuiding applications. ➢ Hardware & Software ➢ Technology deployment .Development ➢ Applications	9:45 – 10:10
Introduction to Cutting application with Cobots	10:10 -10:30
Coffee Break	10:30 – 11:00
Practical Demonstrations	11:00 – 13:00
End of the Day	13:00

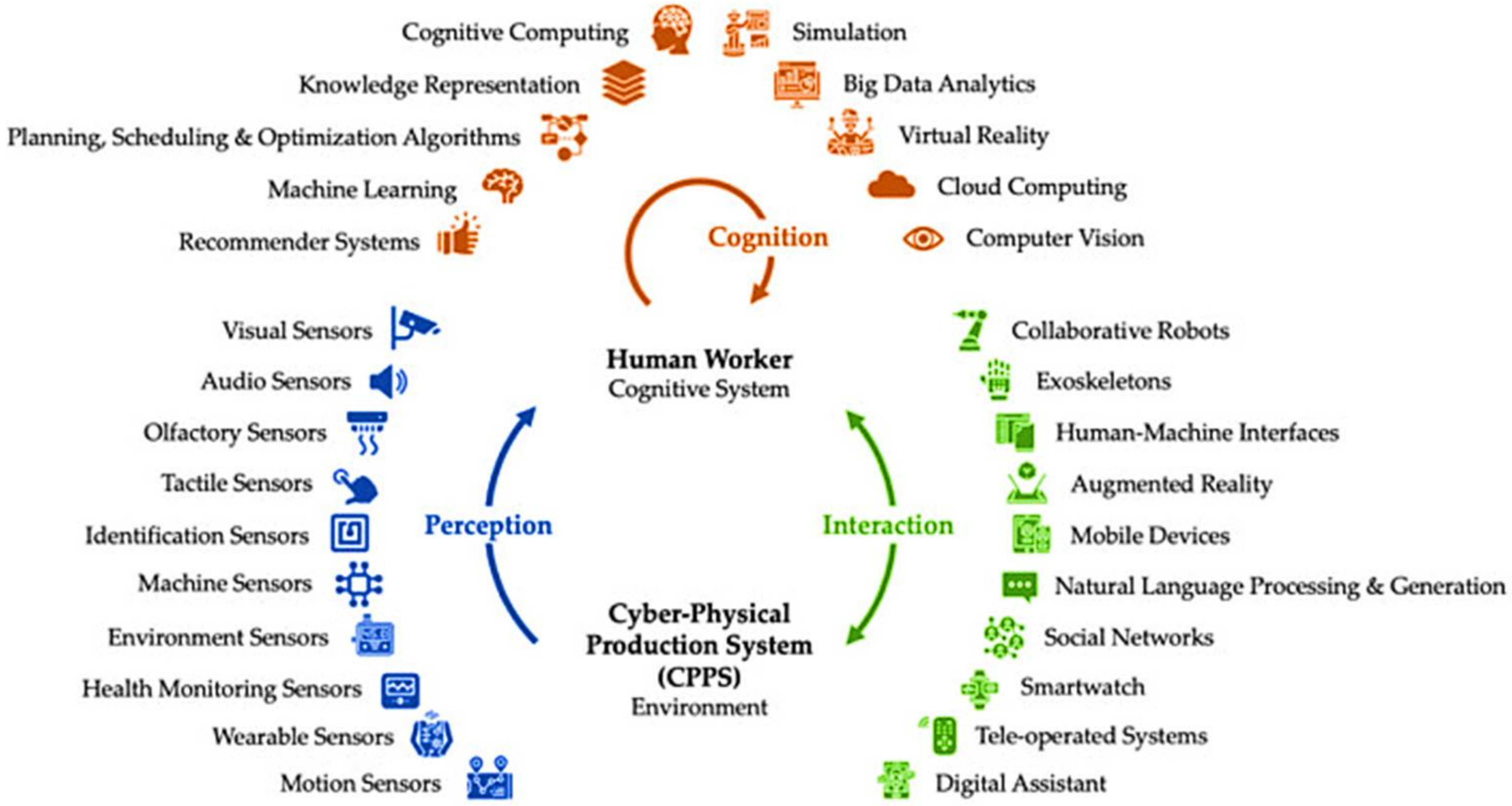
These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

Learning outcomes

- Target Audience
  - SME (end-users) plus Tech. Developers (Human Centric Robotics), students
- Challanges and technology roadmap
- Understanding of the collaborative and embodied intelligence robotics
  - Classification
  - Impact and market
  - Technology claims
  - Commercial products
- Collaborative Workspace design
- Safety and standardization
- Speed and Separation Monitoring
- Hand Guiding
- Power and force limiting
- Potential use-case for collaborative
- Takehome

These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

Human centric enabling technologies – our focus



Source: https://ncbi.nlm.nih.gov/pmc/articles/PMC10146632/

These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

Why are these enabling technologies worth

Major challenges:

Social:

- Aging, skilled labor shortage, skill mismatch

Technological

- Rapid evolution, AI, competitiveness, customization

Industrial

1. Manual work
    - Still too many manual operations
    - Where it is very difficult to help the operator using industrial robots or other means
    - Complex manipulations and high flexibility
2. There are workers with special needs
    - That cannot work in any workspot
    - Vulnerable groups

New physically assisting devices are needed.

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Industrial robots and their evolution during industrial revolutions

Roadmap of evolution of robotics technology

Industrial Robots	Collaborative Robots	Wearable Robots
High speeds = 10x HS	Medium Speed = 2x HS	Human Speed (HS)
Non efficient	Efficient	Optimal
Not safe	Safe	Safer

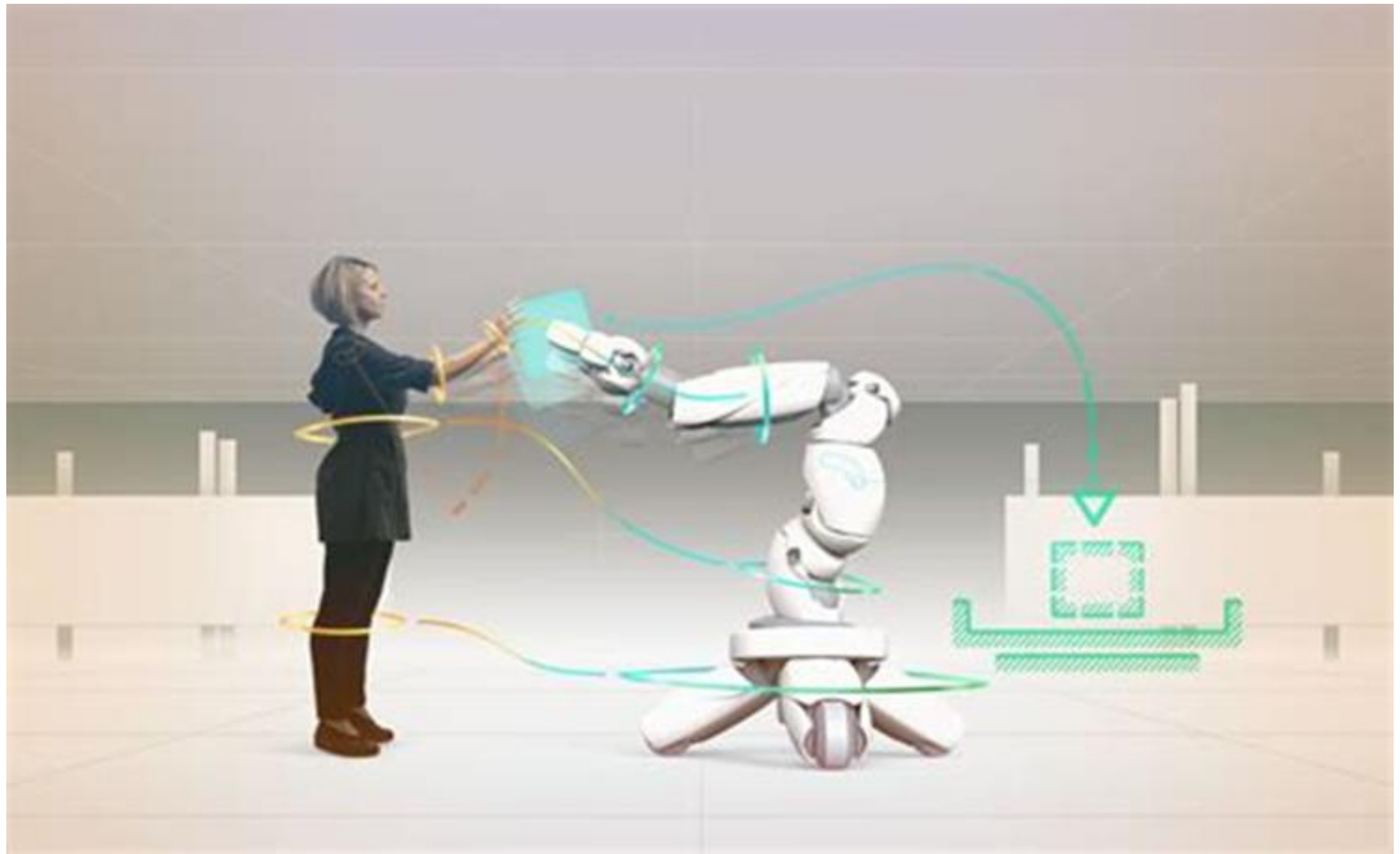
These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

Collaborative Robots

These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

Human-centricity and the collaborative robots

A cobot refers to a robot with the capability of being used in a collaborative operation.



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Types of Collaborative robots

According to ISO10218 part 1 and 2, four type of collaborative robots are:

1. **Safety Monitored Stop (SMS)**

   Safety-monitored stop collaborative robots, are designed for scenarios where human and robot interaction is limited.

   These robots often incorporate industrial robots equipped with various sensors that halt operations if a person enters the robot's working area.

2. **Speed and Separation Monitoring (SSM)**

   Speed and Separation Collaborative robots utilize industrial robots but enhance safety with advanced vision systems. These systems control the robot's speed and halt operations if a human is near, stopping completely if too close.

3. **Hand Guiding (HG)**

   Collaborative robots have hand-guided devices that let operators control the robot's movements in automatic mode. The robot will only follow operator commands during this mode, such as supporting a heavy object while the operator moves it. This setup helps prevent injuries from repetitive strain. Hand guiding happens in automatic mode during production, not during programming or other non-production activities.

4. **Power and force Limiting (PFL)**

   Collaborative robots are designed with safety features such as rounded edges and intelligent collision sensors to detect human contact swiftly and halt operations, along with force limitations to prevent injury in case of a collision

These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

Classification of Collaborative Operations

There are three types of robot operations:

1. **Coexistence**

   Robots and humans operate in the same area without any physical barriers separating them, yet they perform distinct tasks separately. Cobots, being generally lightweight and user-friendly, can simplify and expedite the setup, programming, and recycling of robots, requiring minimal training for operation.

2. **Cooperation**

   Human-robot cooperation refers to a scenario where humans and robots work together within the same area. Throughout the task progression, they alternate between completing their duties without requiring immediate interaction. In such an environment, the necessity for physical barriers, such as fences, is minimized, as the collaborative robot, also known as a cobot, is designed to be safe, or the working area is equipped with protective sensors.

3. **Collaboration**

   In a collaborative environment, humans and machines cooperate side by side. Tasks may involve handoff processes where the robot transfers responsibility to the human worker, or they may engage in joint operations on machinery.

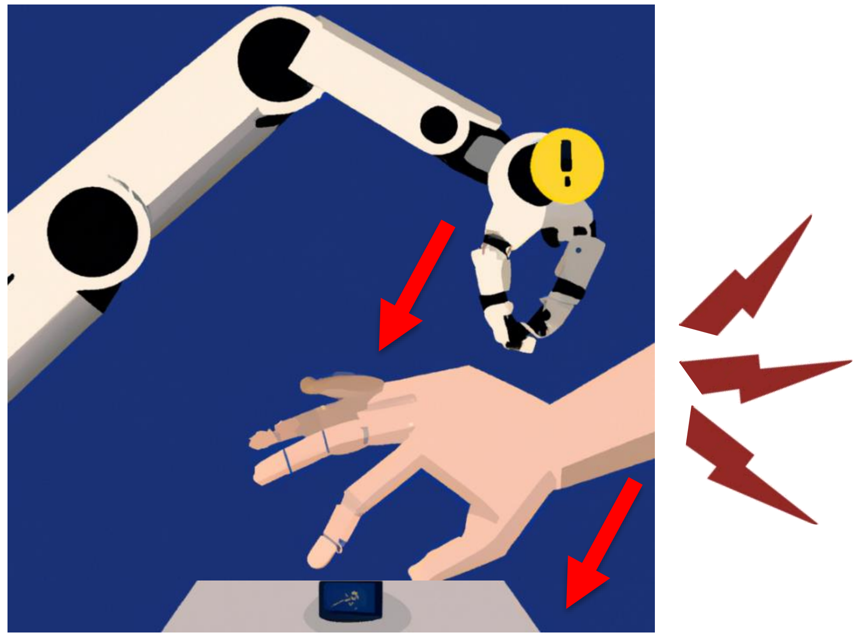
Reference: https://www.zetagroupengineering.com/levels-of-collaboration-robots/

These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

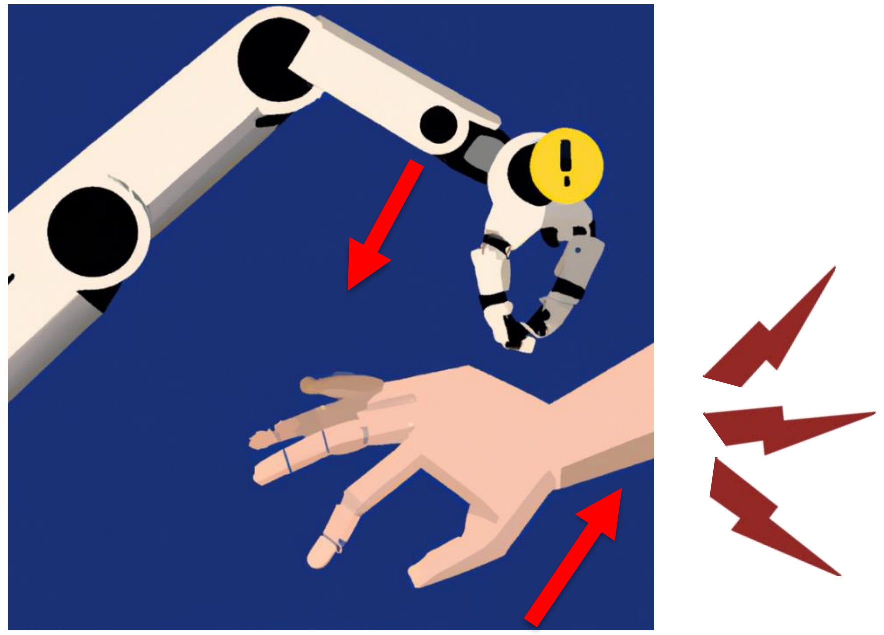
Type of Interactions

Two major types:

- **Quasi-static**
  - When user body clamp between moving robot part and the another fixed or moving part of the robotic system.



- **Transient contact**
  - When the user body does not clamp, which means the user can quickly retract or recoil from the moving part of the robotic system.



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The Collaborative Robotics Market

	Collaborative Robotics Technology
Collaborative Robots	SMS, SSM, PFL, HG
2022 Market (in USD million)	900 (2023) to 7000 (2030) 3x – Europe 30% global
2022-2030 Market (in units)	4500 (2023) units to 42,000 (2030) units 9.3x
Main application areas	Material Handling. In Europe, logistics, electronics and inspection
Main operations	Present: Pick and place (31% revenue), assembly (23% revenue) Future: welding and gluing
Payload capacity	Upto 5kg (44%), upto 10kg, above 10kg

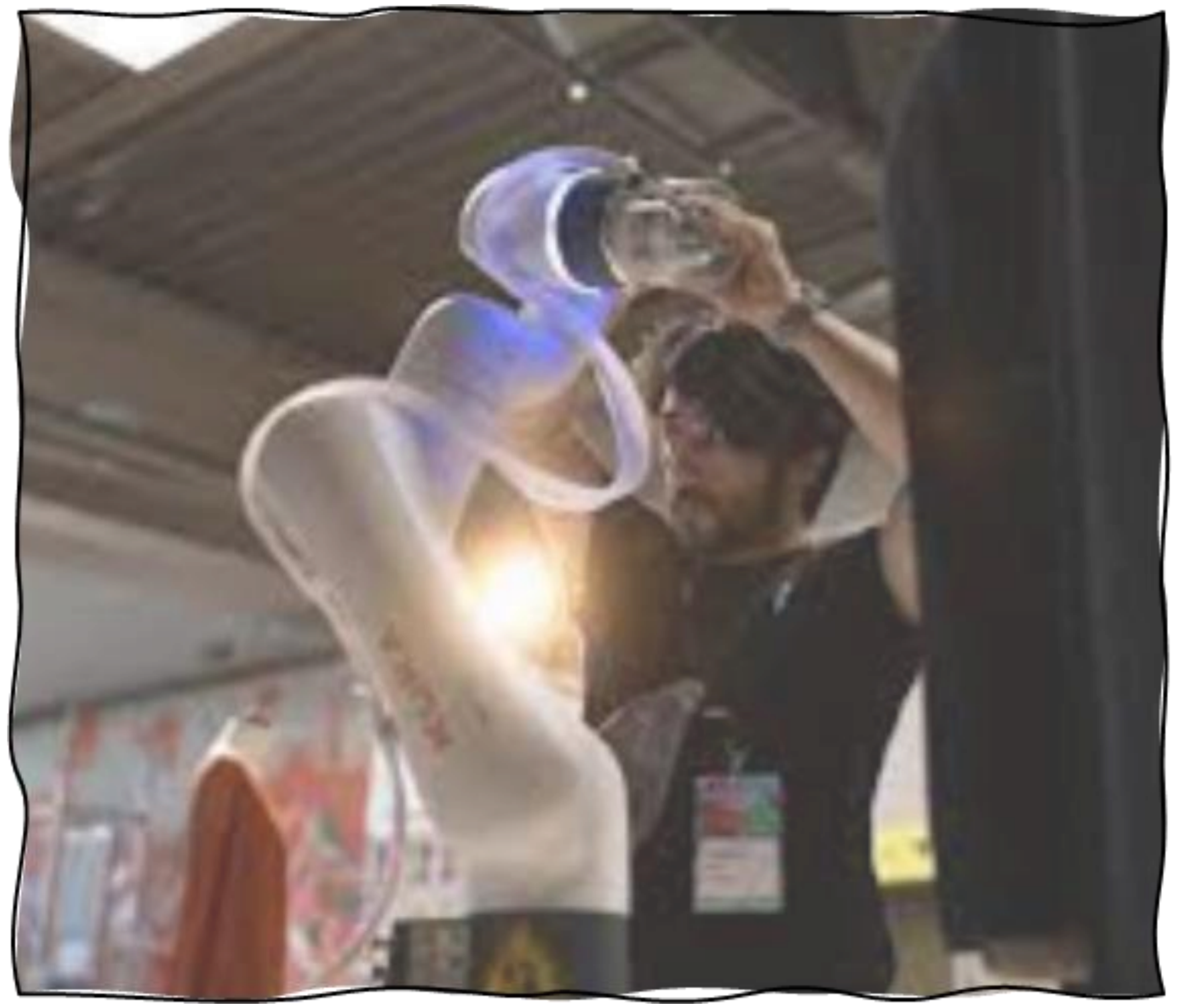
source:

1. https://www.statista.com/topics/8062/collaborative-robots-worldwide/#topicOverview
2. https://www.grandviewresearch.com/industry-analysis/collaborative-robots-market

These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

Technology claims

- Enhancing Human-Robot Interaction
- Flexibility and Adaptability
- **Assist not Replace**
- Reduced Workforce Requirements
- Cost Savings
- Training and Skill Transfer



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Commercial devices available


Courtesy: ABB Group


Courtesy: Kuka


Courtesy: Franks Emika Gmbh


Courtesy: Denso Robotics


Courtesy: ReThink Robotics


Courtesy: FANUC


Courtesy: Yaskawa Electric Corporation


Courtesy: Universal Robots


Courtesy: Comau S.p.A.

These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

Embodied Robotics

These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

Human-centricity and the embodied robots

Exoskeleton are the devices that are wearable which can support and assist movement or augment the capabilities of the human body.

These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

Classification

These devices can target the arms, shoulder, back or legs.

Such devices can broadly classify based on their actuation as:

1. **Passive**

   Do not have an electric power source and can be used for weight distribution, energy capture, dampening, or locking

2. **Active**

   Use batteries or external power source to run sensors and actuators of the exoskeleton

3. **Quasi-Passive**

   Have batteries, sensors, and or other electronics but actuations is either absent or not being powered by the external source.

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The Exoskeleton Market

Exoskeleton Technology			
Industrial Exoskeletons	27% Shoulder, 26% Trunk, 25% Hand/Arm, 22% Legs		
Status	54% Commercial	46% Development	
2017 Market (in USD Billion)	17.9 Medical	0.1 Industrial	18 Total
2025-2028 Market (in USD Billion)	31.2 Medical	1.76 Industrial	33 Total
Weight	19% > 10 kg	10kg < 34% > 5 kg	47% < 5 kg
Actuation	55% Active		45% Passive
Actuation technology	55% Electric motor	17% Hydraulic/Pneumatic	100% Mechanical

source: WiseGuy Research Consultants Pvt Limited, ABI Research, exosksletonreport.com

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Technology Claims

- Reduce MSD's
- Improve Posture
- **<u>Assist not Replace</u>**
- Retain Aging Skilled Workers
- Improve Productivity
- Improve Turn Over
- Increase Job Quality

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Commercial devices available

Hand Support
- IronHand (*Bioservo*)



Arm and Shoulder Support
- shoulderX (*suitX*)
- AIRFRAME (Levitate)
- ekosVest (*ekso bionics*)

V2.4

V2.6




Trunk and Back Support
- Laevo v2.4, v2.6 (*Laevo*)
- backX AC and S (*suitX*)
- CRAY X (*German Bionics*)
- HAL (*Cyberdyne*)


Leg Support
- legX (*suitX*)
- Chairless chair (*Noonee*)

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Potential use-cases for exoskeletons

Manufacturing	Agri-food	Maintenance
Maintaining the posture, assembly	Pick and place of the agri-food	Teleoperations
Repetative task loading unloading	Harvesting	Virtual and Augmented reality
Order preperation	Order preperations	Teaching and skill transfer
Augmentation of force or limb	Augmentation of force or limb	Augmentation of force or limb

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Comprehensive training on this subject will be conducted in future

18, 19 June 2024 | 9:30 - 12:30 (local time) | BioRobotics Institute of Scuola Superiore Sant'Anna, Pontedera (Pisa, Italy) | Hybrid

These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

Challenges

- Finding the best use-case
- Safety

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Challenges

- Finding the best use-case

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Key technology challenges in use-case design

Beside safety there are six key challenges:

- Proper configuration selection for a given task
- Manual skill learning and translation
- Collaborative design tool
- Cell layout optimization and scheduling
- Tooling optimal design
- Human-robot collaboration scoping

These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

What stakeholder do to overcome these challenges

1. Analyze and define the manual task map
    - Example of manual fruit pick and place
    - Number of man hour and sequence of the task
2. Begin the robotic task map
    - Identify the tasks based on their impact on the involved workers, production, and environment
3. Define the high-level task map
    - Prepare a high-level map clearly defining the level of collaboration between human and collaborative robot (remember coexistence, cooperation, and collaboration)
4. Design the layout (and update the task map)
    - Update the use-case layout and identify the possible hazards and perform risk assessment

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Challenges

- Safety

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Safety Pyramid

The safety pyramid has the 3 tools.

1. **Elimination**, which refers to physically removing a hazard.

2. **Engineering controls**, which incorporate programming, safety curtains, etc.

3. **Enterprise Controls**, which changes the way an operator works through work instructions, restrictions, etc.

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Hazards and Risk Assessment

A **hazard** is scenario capable of causing harm or an injury to the user, or damage to the robotic system and or environment.

A **risk assessment** is conducted to evaluate the hazards around robots.

1. **Injury severity**
   - Degree of possible harm to the user
2. **Exposure**
   - Frequency or duration, likelihood of a user exposed to the hazard
3. **Avoidance**
   - Ability of the user to detect and avoid the hazard

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Standards and Benchmarking - Reproducibility

Collaborative Robots
ISO 10218-1:2011 part 1 talks about the safety essentials for industrial robots
ISO 10218-1:2011 part 2 incorporates the safety requirements at the integrator level.
ISO/ TS 15066-2016 builds upon the two previous standards and provides safety requirements for collaborative industrial robots.
COVR toolkit (https://www.safearoundrobots.com/toolkit/home), **EuroBench** (https://cordis.europa.eu/project/id/779963)

These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

Types of Collaborative robots

According to ISO10218 part 1 and 2, four type of collaborative robots are:

1. Safety Monitored Stop (SMS) - Isidro

2. Speed and Separation Monitoring (SSM) - Claudio

3. Hand Guiding (HG) - Afra

4. Power and force Limiting (PFL) – Afra

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Classical safety devices in a robot cell (SMS)

Isidro Fernández Iglesias
O Porriño, 10th April 2024

These projects have received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

aimen
TECHNOLOGY CENTRE

Contents

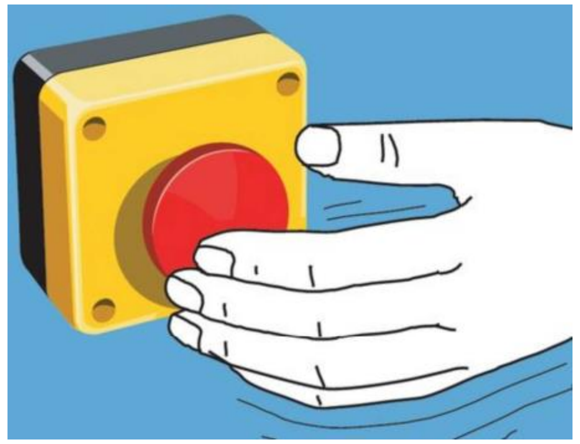
These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

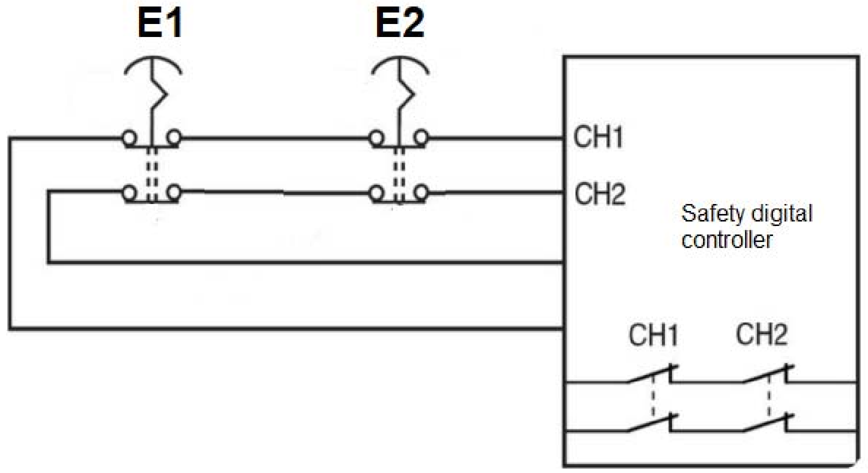
1-Conventional safety devices: Mandatory devices

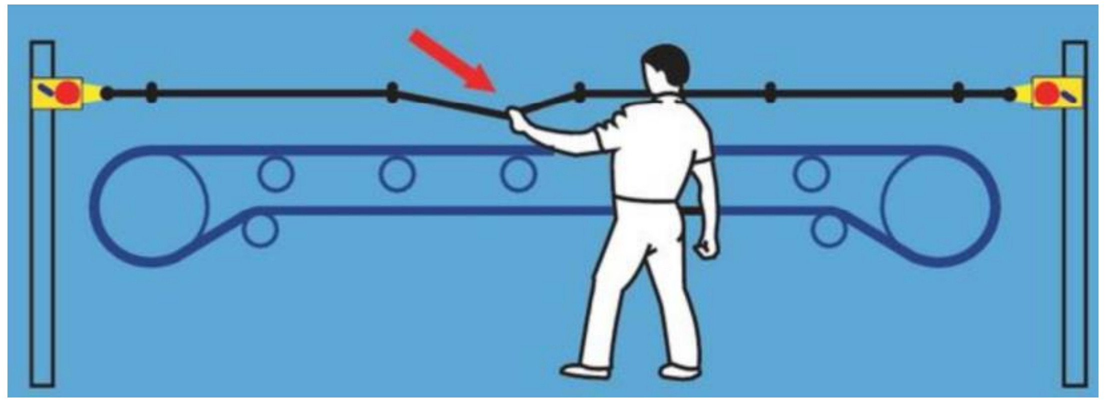
When a robot (potentially lethal machine) can be dangerous for an operator, and it is impossible to isolate the robot from harming someone on the surroundings, like a maintenance operator for instance, hazardous should be eliminated. To do that different safety devices can be used in a robot cell.

Next devices can be found in a usual robotic cell:

1. **Emergency stop buttons**: this kind of devices perform a quick stop of robot and any other machine working inside the robot cell (a process machine for instance). It also disconnects all the energy supplies to the robot motors and to the machines (electric, pneumatic or hydraulic power). There should be at least one of this emergency stops in the robot cell. They are actuated by pushing it with hands. They are armed again with a conscious movement turning it around.
2. **Emergency stop cords**: this kind of devices are similar to the ones above but have the advantage of reaching bigger areas because of its length. They are usually installed when a conveyor or a gantry is inside the cell.







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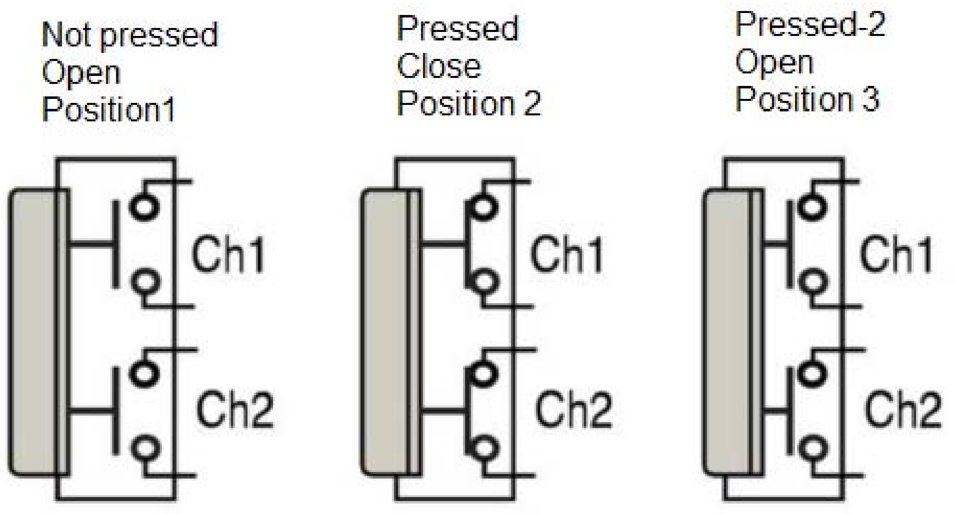
1-Conventional safety devices: Mandatory devices

3. **Three-position enabling device**: this device is installed on the robot teach unit and it should be pressed by the robot operator when he/she wants to move robot. It only works with the robot in MANUAL mode, as in AUTOMATIC it is canceled. When pressed in MANUAL, robot motors are activated, and robot can be moved.



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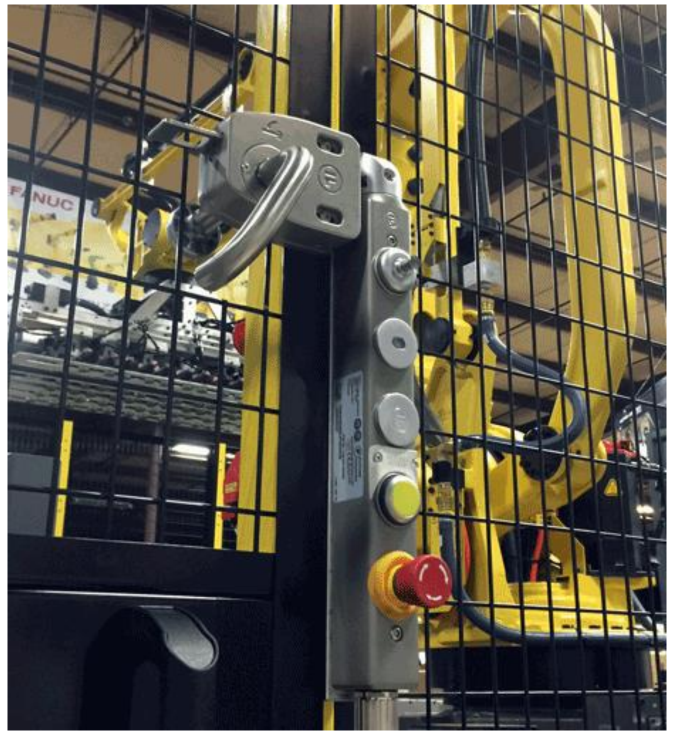
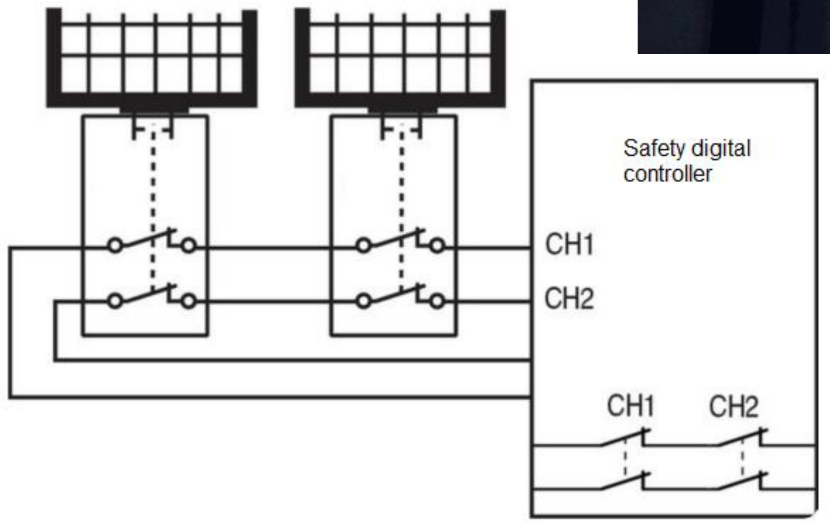
1-Conventional safety devices: Additional devices

There are a set of different safety devices we can install in a robotic cell, to protect the robot working area from accidental intrusion of one person during the AUTOMATIC robot working. Some of them, or all, can be found in a robotic cell depending on every use case:

1. **Physical guard fences**: it is usual to have robots working in enclosed spaces, with fences guarding from possibles incidents like people accessing into the robot working area, or from some parts throwed outside, or process hazardous (laser, welding splashes, gases…).
2. **Safety door interlock switch**: if physical fences are installed, an entrance is needed to the operator get into in case of necessary (maintenance). To protect this entrance a safety door switch is needed. This device just let go inside the robot cell when robot and other machines are stopped and in MANUAL mode. To make robot working again in AUTOMATIC the door has to be closed.





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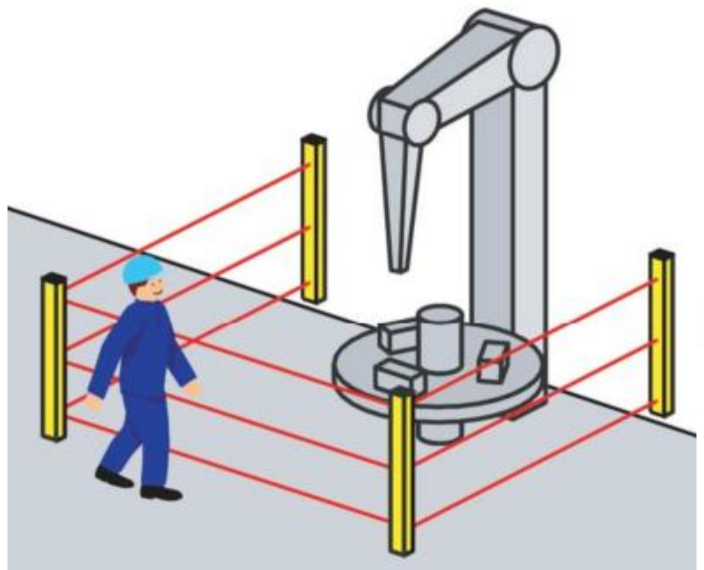
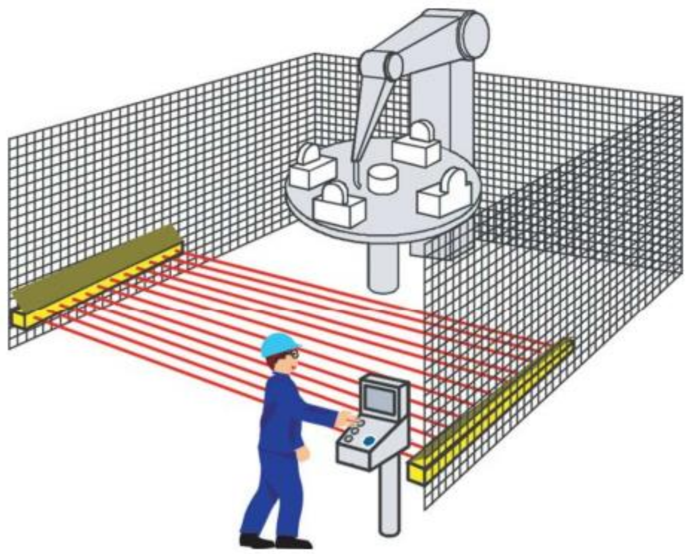
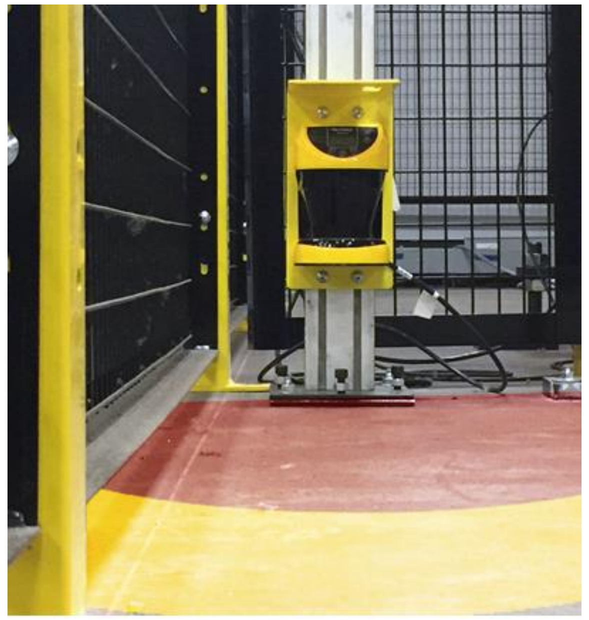
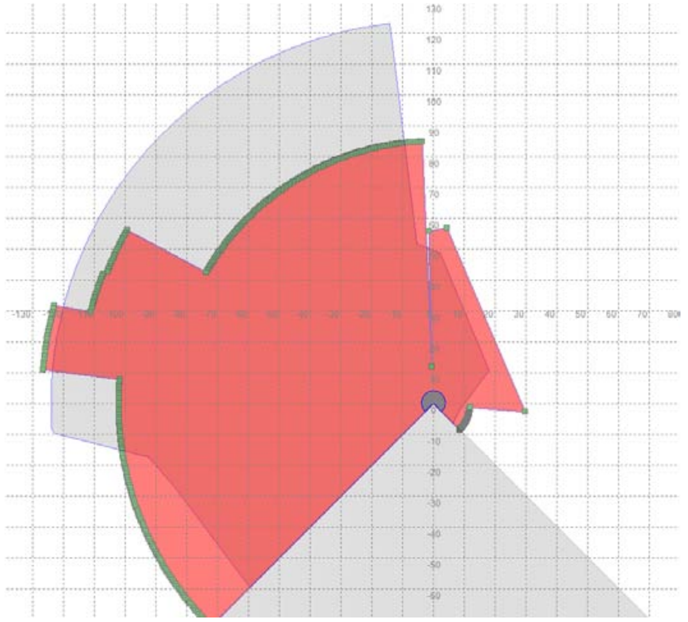
1-Conventional safety devices: Additional devices

3. **Safety light curtains**: In case is needed continuously accessing to the robot working area inside a robot cell, better than having a door, is better to install light curtains to protect an entrance. They consist of a transmitter and a receiver faced off each other, covering the whole entrance space, detecting if someone or something interrupts the light curtain, stopping the robot or other machine. Once the curtain is free again, operator has to confirm pressing a button to robot working resumes.
4. **Laser scanners**: This safety devices are intended to protect a robot working area in a similar way the light curtains do but being more versatile and flexible. The surveillance area can be defined and adapted to the real scenario using a dedicated software. They control two areas: warning area, and security area. There is just one transmitter that reads the time-of-flight of a laser beam which is emitted in in a rotary way creating a surveillance "surface".

These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

1-Emerging safety devices: SafetyEye

New emerging safety devices are appearing constantly as off-the-shelf devices ready to be purchased. Some of them are next:

1. **Safety radar**: this kind of device based on radar technology (very low energy radio waves) is able to measure a volumetric space to detect the entrance and presence of operators in dangerous areas and stop machinery. Transmitter and receiver are built in the same unit and are able to detect human body micro-movements.

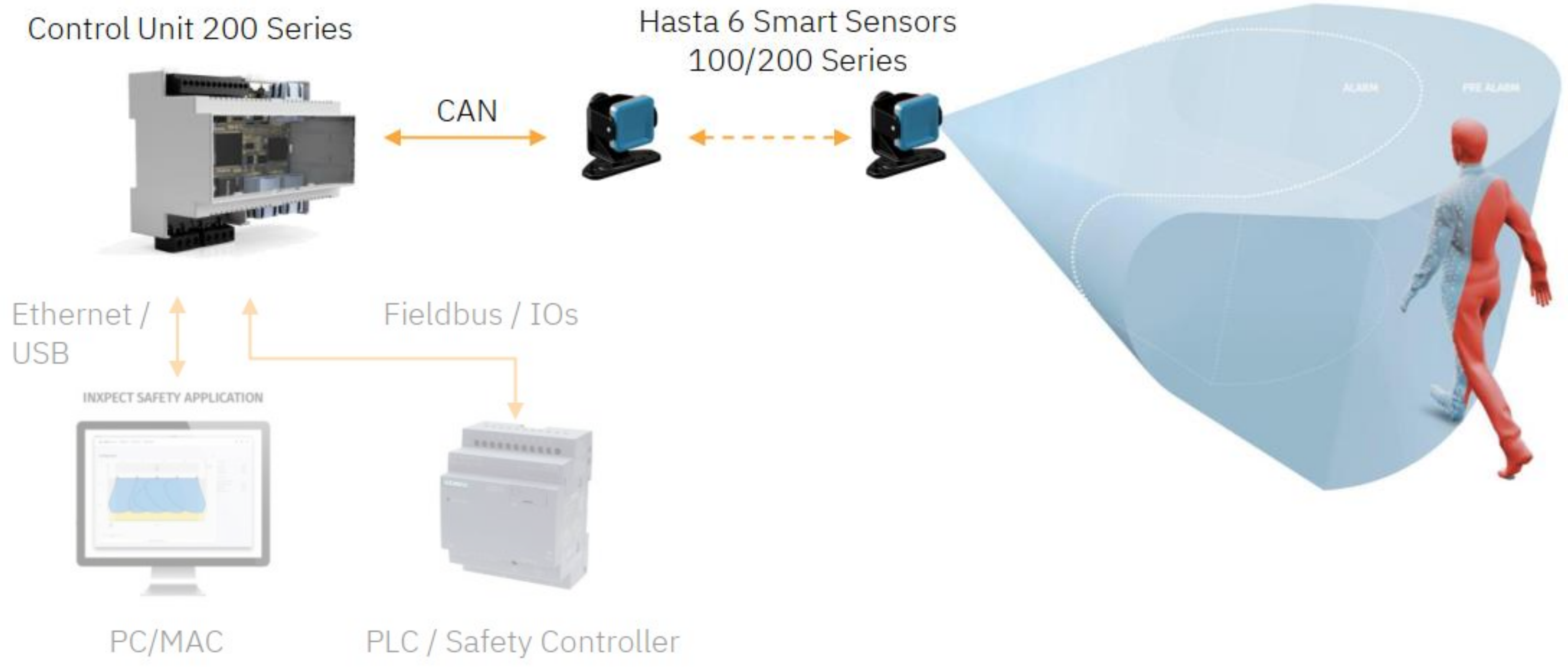
This technology is composed by two units:

1. Smart sensor:

The radar unit responsible of detecting people or objects by using radio waves.

2. Control unit:

The control unit is the responsible of reading the information from smart units, read any digital inputs for muting or reset…etc, and switch on/off robot.



These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

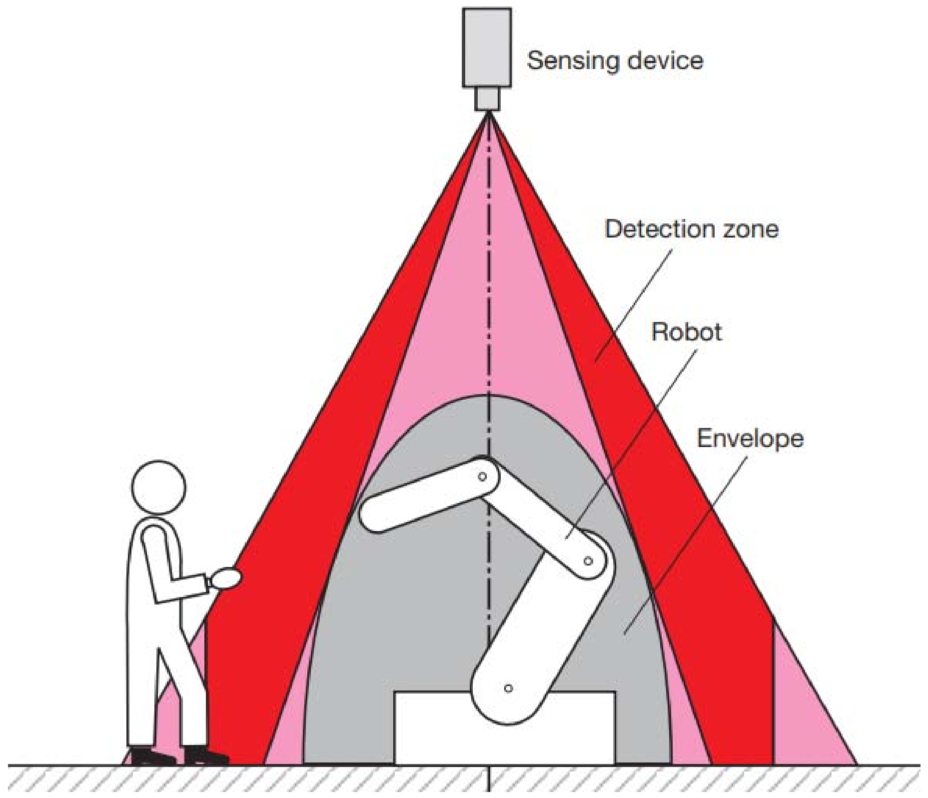
1-Emerging safety devices: Safety Radar

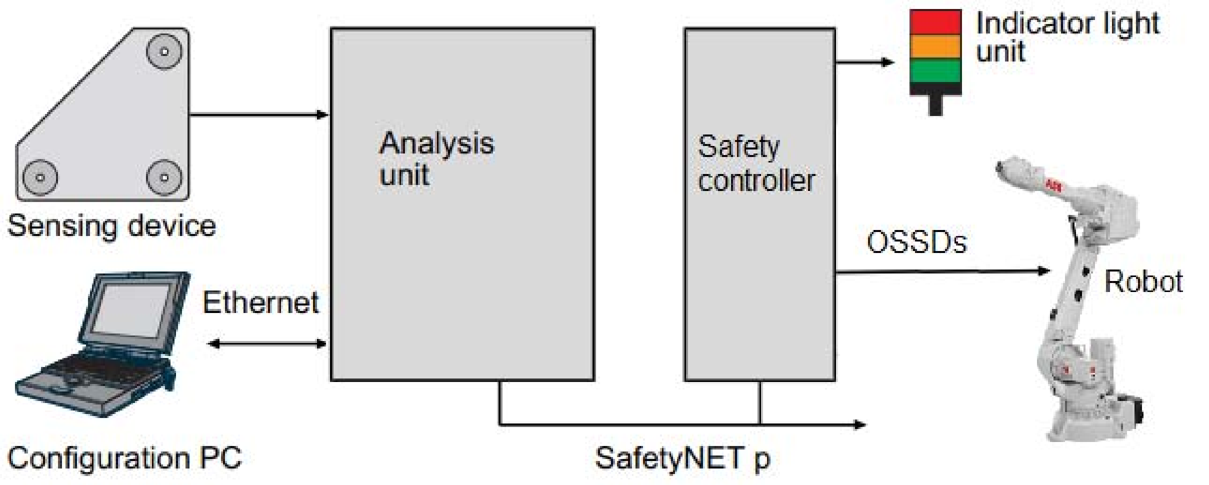
2. **SafetyEye**: this kind of device is able to measure a volumetric space to detect whether something or someone is invading the monitored area, the robot working area, to stop robot or any other machine moving. To do that next components are needed to be installed into the robotic cell:
   1. Sensing device:

   SafetyEYE's sensing device consists of three cameras, which supply the image data of the zone that is to be monitored.
   2. Analysis unit:

   The analysis unit is where the image data is evaluated and the results (e.g. detection zone violation) are sent to the programmable safety and control system.
   3. Programmable safety and control system:

   The programmable safety and control system provides the inputs/outputs (output switching elements OSSDs, control of the indicator light unit, input for the reset button, etc.).





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Speed and Separation Monitoring (SSM)

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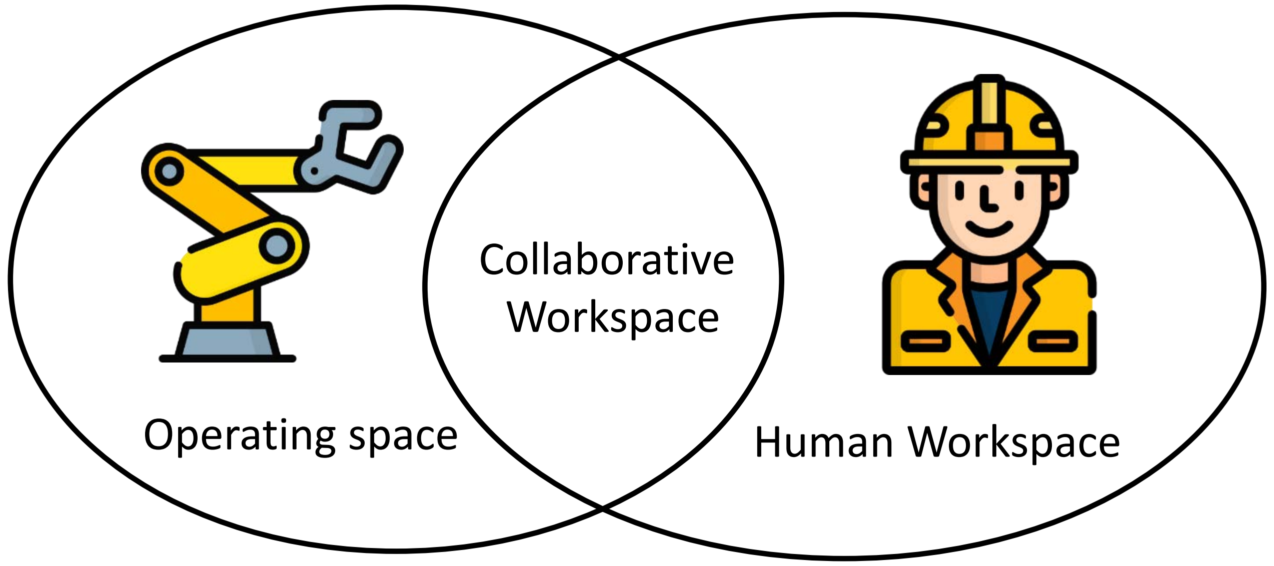
CLOSED-LOOP DIGITAL PIPELINE

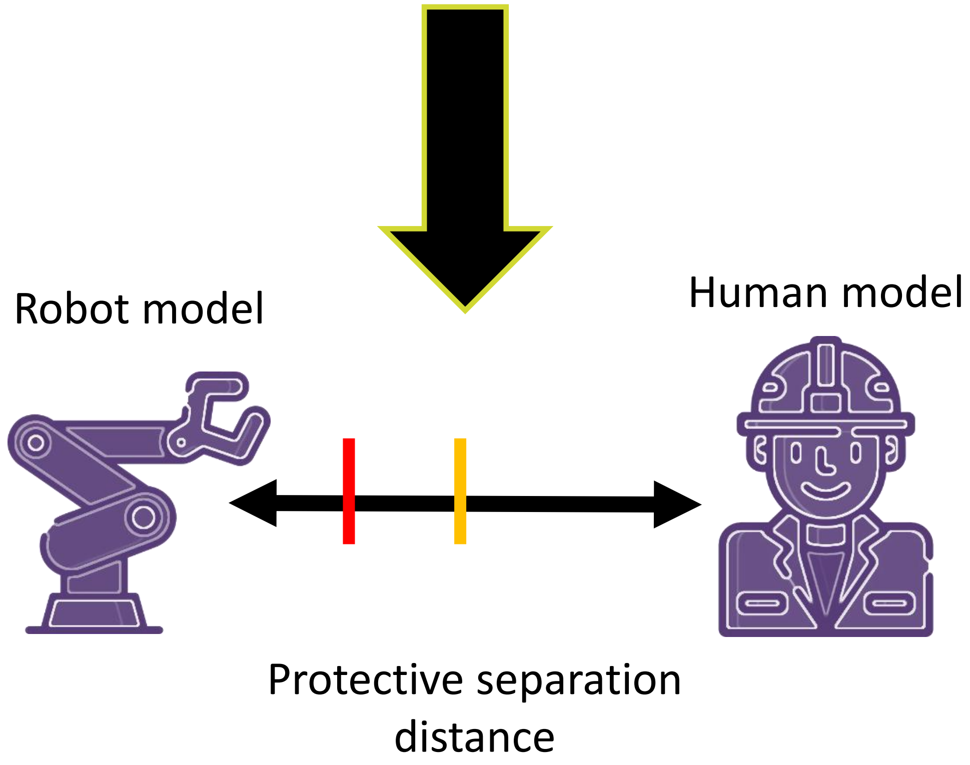
Claudio Sánchez
O Porriño, 10th April 2024

These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

Concepts

- Operating space
- Collaborative workspace
- Collaborative operation
  - ISO 10218, ISO TS 15066
  - Hand guiding (HG)
  - Safety-rated Monitored Stop (SMS)
  - Power and Force Limiting (PFL)
  - **Speed and Separation Monitoring (SSM)**
- SSM
  - Body model
  - Robot model
  - Protective separation distance
  - Advantages:
    - better productivity
    - can be combined with other safety methods





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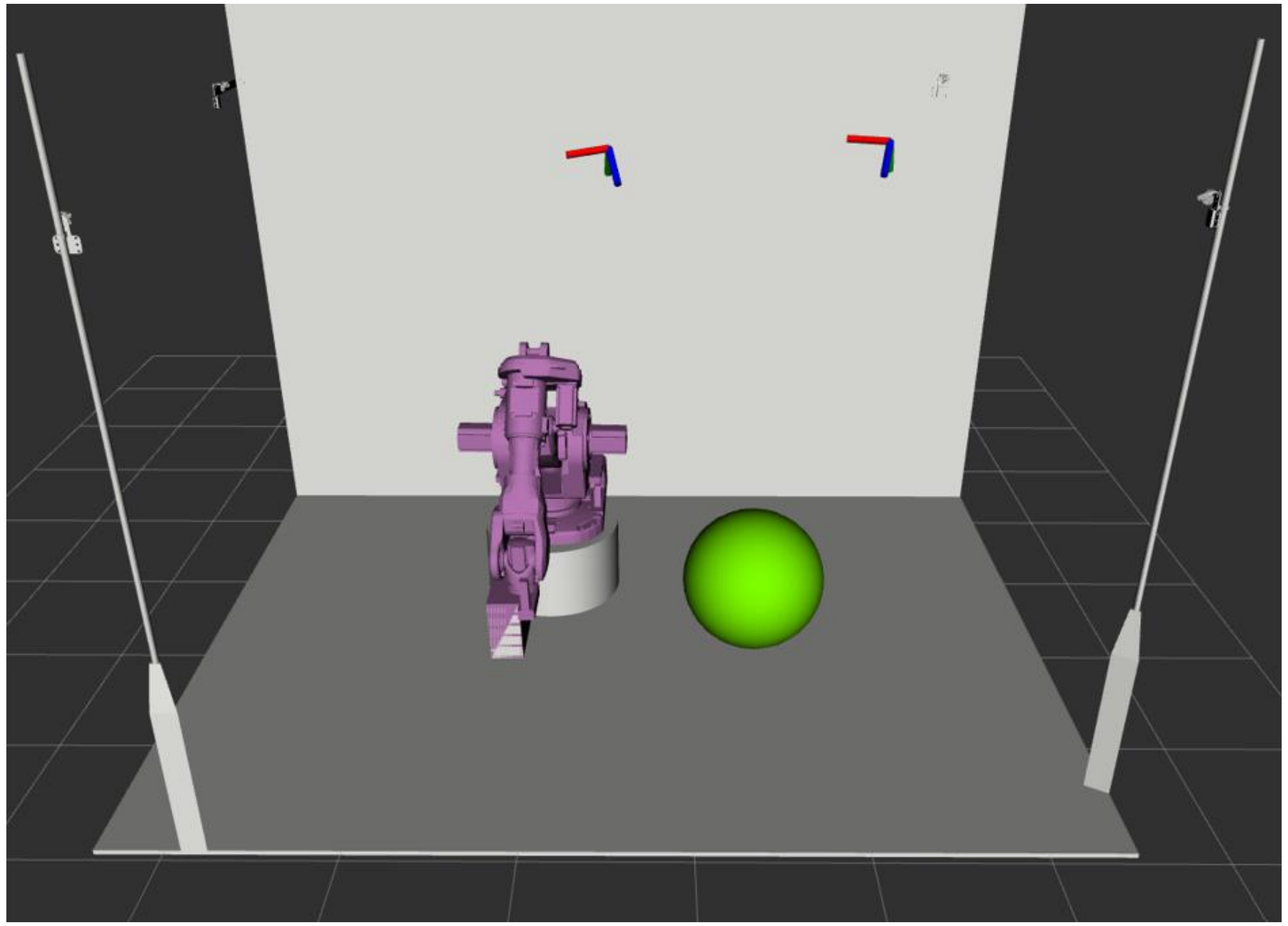
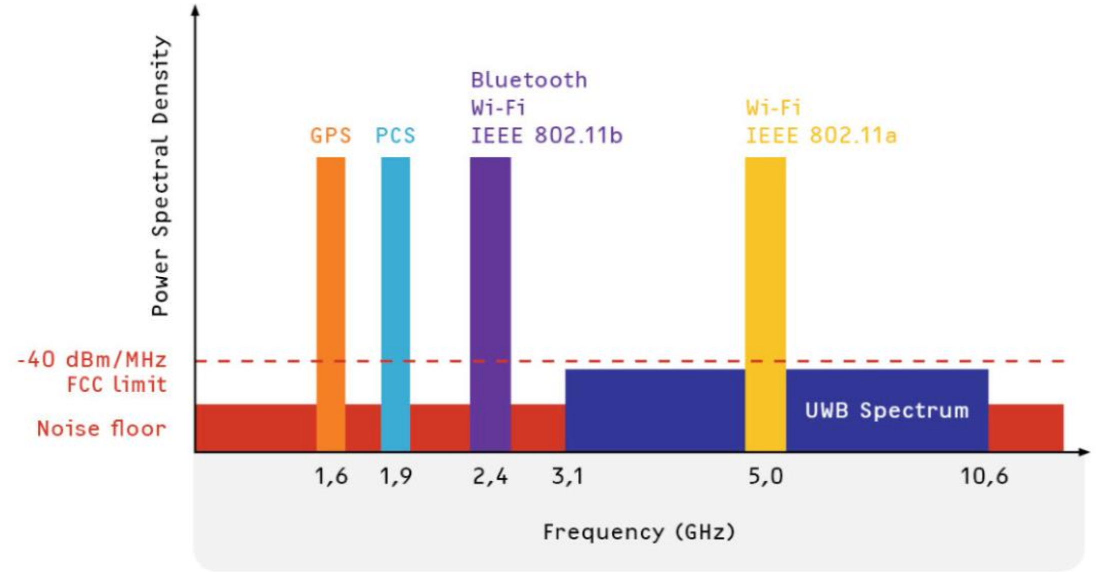
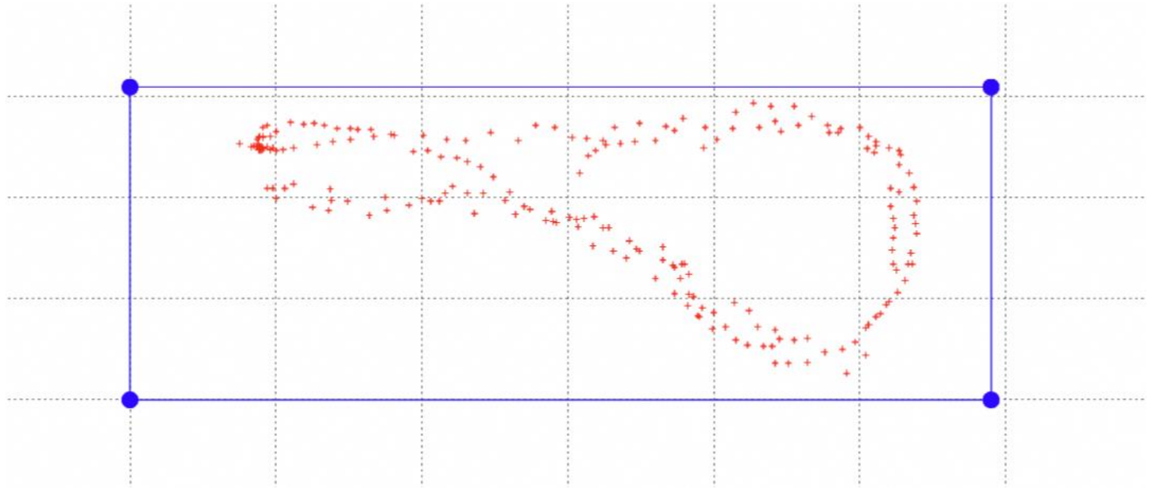
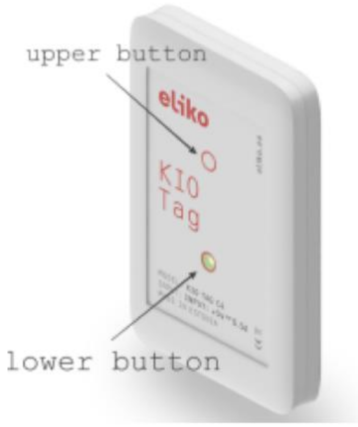
UWB

- Ultra Wide Band: 3.1 - 10.6 GHz
- Tag + Antennas
- Low consumption
- Low cost
- High range (70 m)
- Applications: logistics, manufacturing, transportation, safety
- Limited precission (>60cm)









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Computer vision systems

- RGB
- High resolution
- Robust construction
- Advanced software integration
- Flexible connectivity
- Real-time imaging
- High cost
- Complex setup
- Sensitivity to environmental factors
- Maintenance requirements
- Oclussion issues

- OpenCV – Open source (BSD) computer vision library
- More than 2500 algorithms
- C, C++ and Python APIs
- Cross platform

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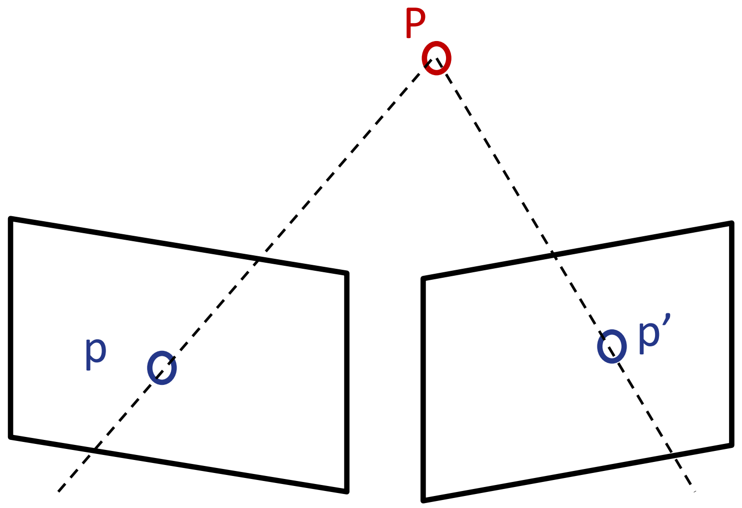
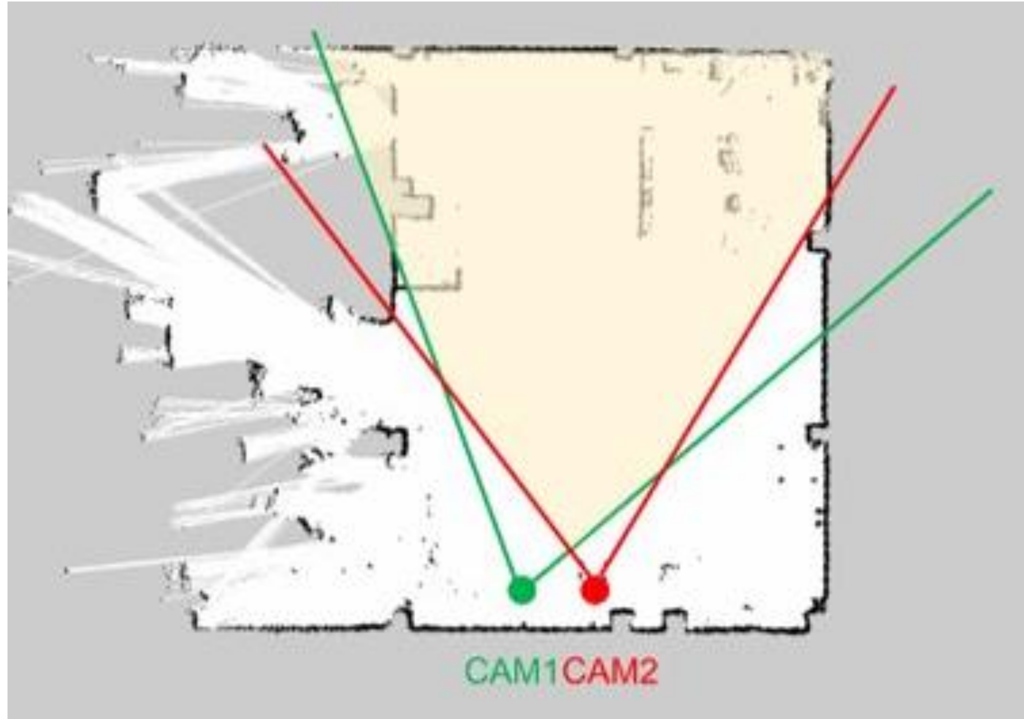
Stereo vision systems

- Depth perception
- 3D reconstruction
- Calibration complexity
- Occlusion issues
- Limited range





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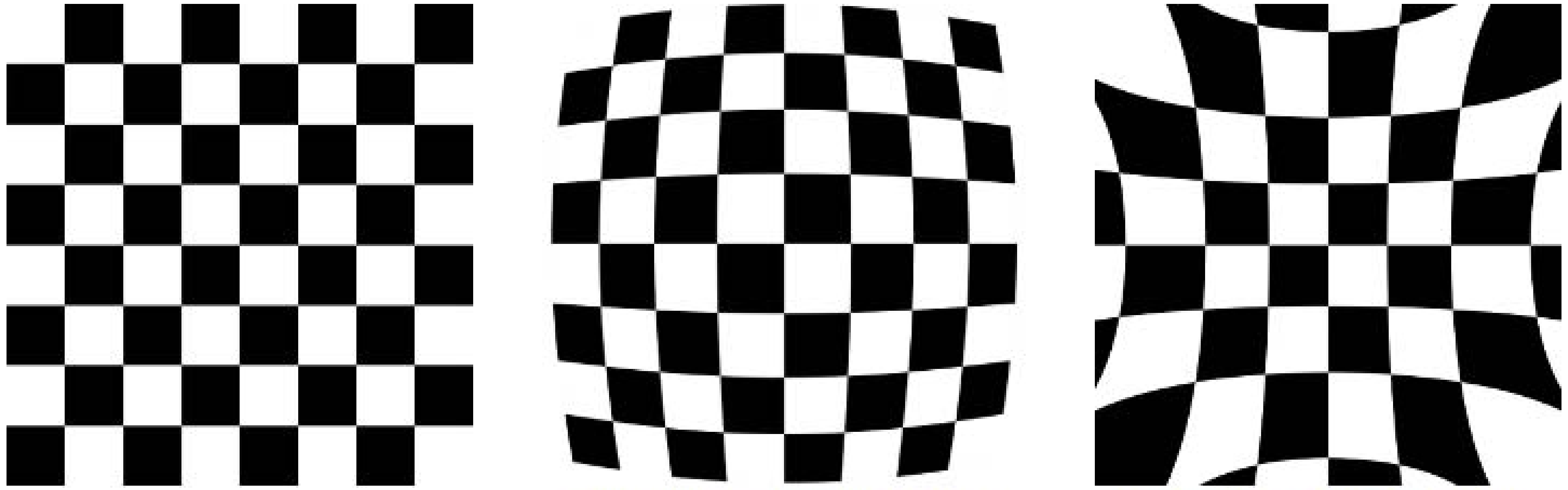
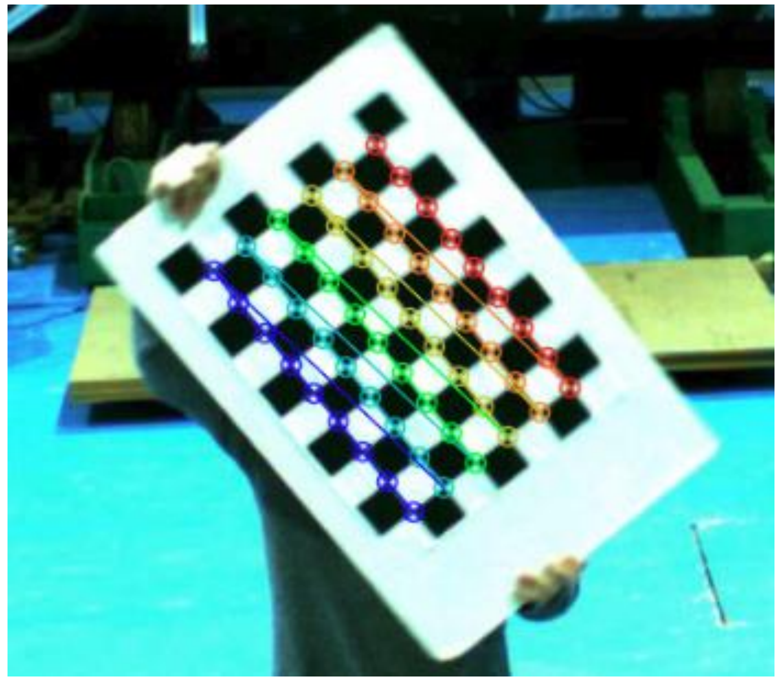
Intrinsic calibration

OpenCV

- Intrinsic calibration determines internal parameters of a camera crucial for accurate image interpretation.
- Crucial for accurate 3D reconstruction, object localization, and pose estimation in computer vision and robotics.
- Process: Image Acquisition -> Feature Extraction -> Correspondence Estimation -> Parameter Estimation and optimization -> Validation



No distortion | Negative radial distortion (Barrel distortion) | Positive radial distortion (Pincushion distortion)



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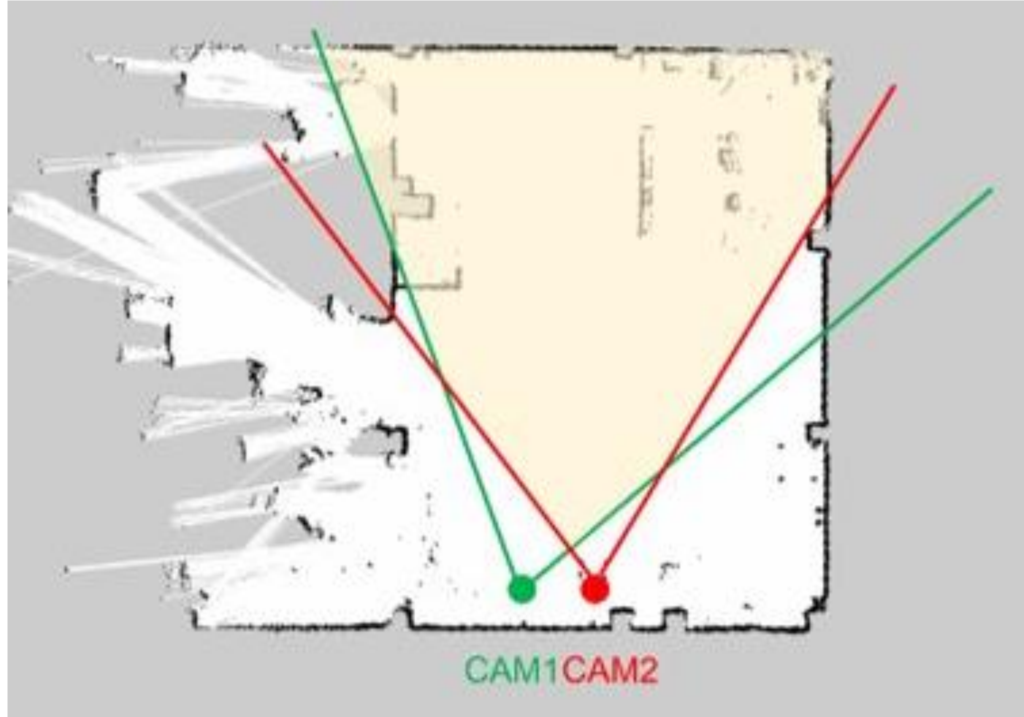
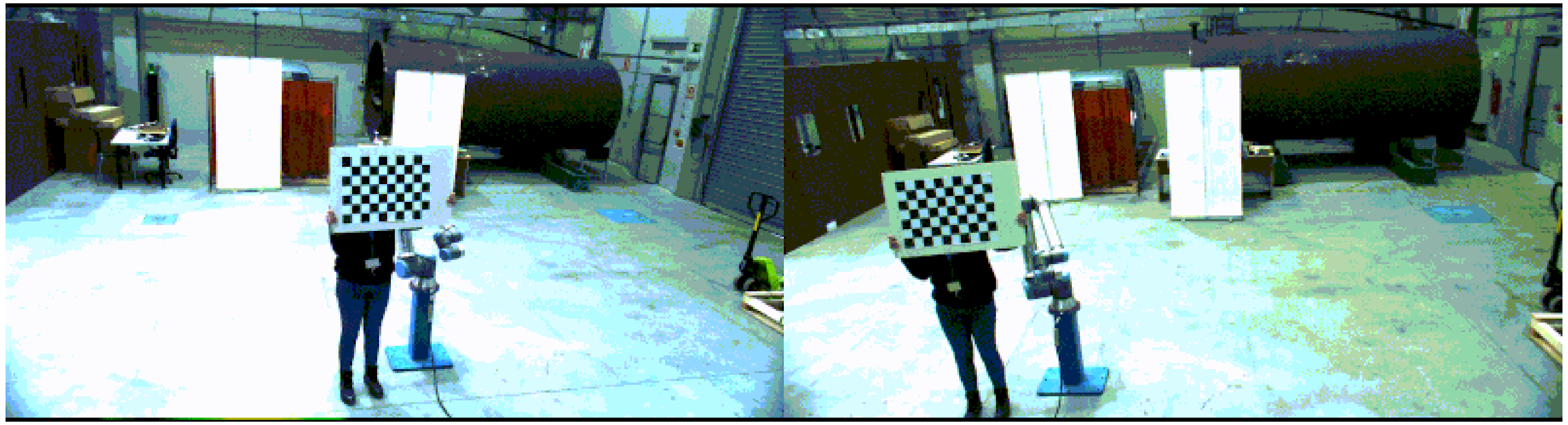
Extrinsic calibration

OpenCV

- Extrinsic calibration determines the relative pose between multiple cameras or between a camera and another sensor or coordinate system.
- Process: Image Acquisition -> Feature Extraction -> Correspondence Estimation -> Pose Estimation -> Optimization -> Validation





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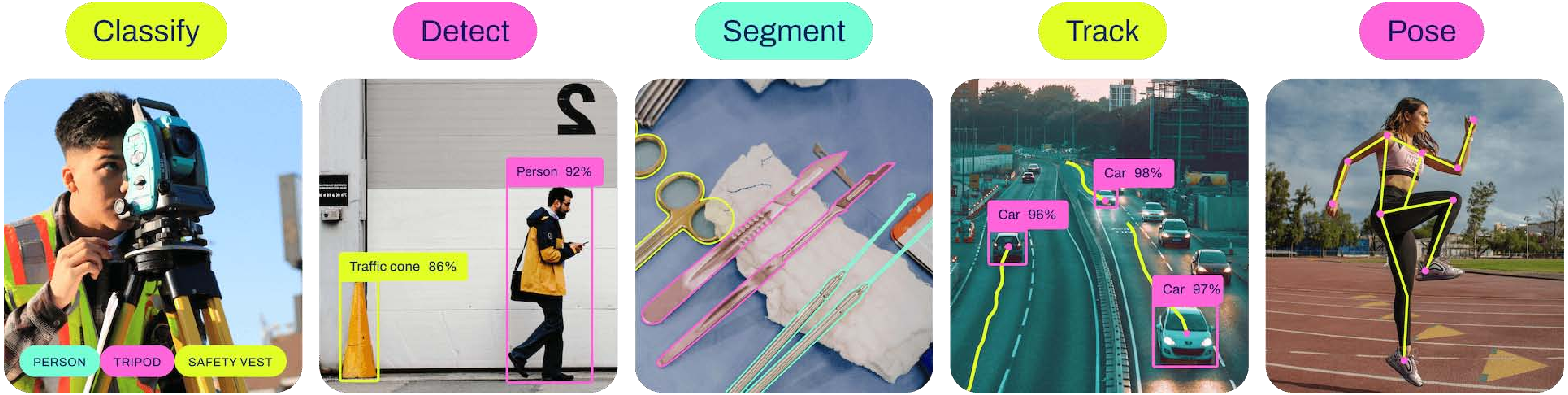
YOLO

- State-of-the-art object detection and image segmentation algorithm that revolutionized real-time object detection.
- Applications: Surveillance, object tracking, intrusion detection, crowd monitoring, traffic sign recognition, pedestrian detection, and obstacle avoidance, shelf monitoring, product recognition, inventory management.

- Real-time
- Accuracy
- Small objects
- Objects at different scales
- Environmental conditions
- Computationally intensive



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Results

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FCL – Flexible Collision Library

- It is a C++ library for performing three types of proximity queries on a pair of geometric models composed of triangles.
- Collision detection: detecting whether the two models overlap, and optionally, all of the triangles that overlap.
- Distance computation: computing the minimum distance between a pair of models, i.e., the distance between the closest pair of points.
- Tolerance verification: determining whether two models are closer or farther than a tolerance distance.
- Continuous collision detection: detecting whether the two moving models overlap during the movement, and optionally, the time of contact.
- Contact information: for collision detection and continuous collision detection, the contact information (including contact normals and contact points) can be returned optionally.

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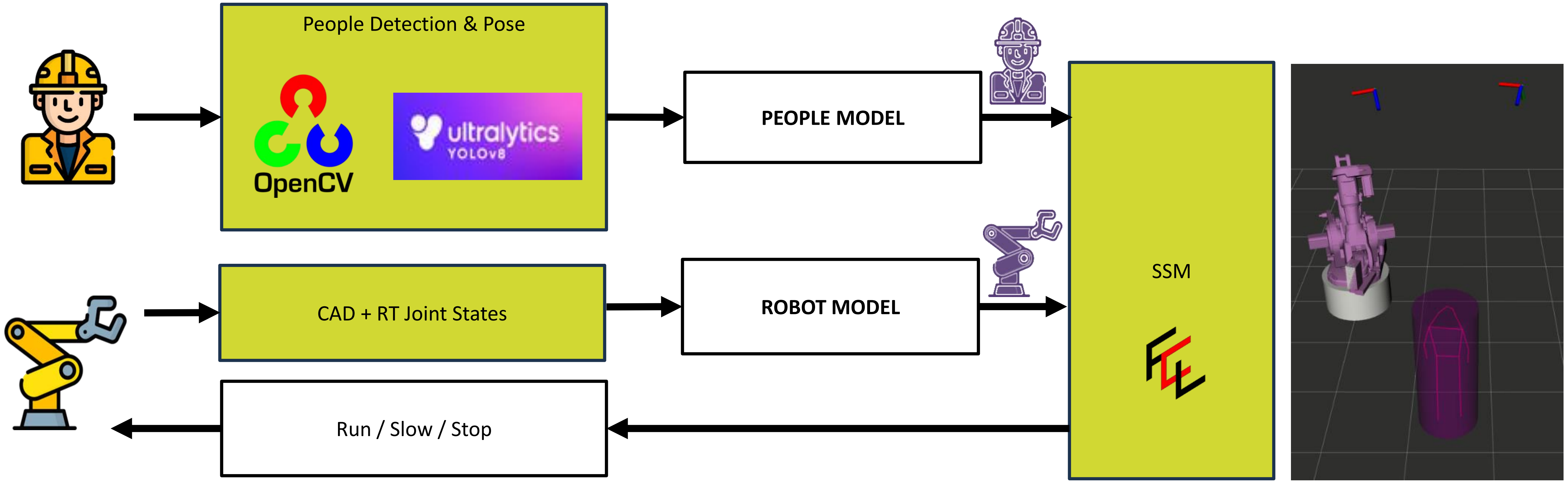
ROS

- Open source framework for robotics
- Message passing interface between processes
- High-level programming language support and tools
- Availability of third-part libraries
- Community support
- Extensive drivers, tools, simulators



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Hand Guiding of Industrial Robots (HG)

Afra María Pertusa Llopis

O Porriño, 10th April 2024

These projects have received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

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CONTENTS

1. Introduction
2. Hardware
3. Software
4. Technology deployment
5. Development
6. Applications

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CENTRO TECNOLÓGICO

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INTRODUCTION

- Solution to move the robot by direct interaction.
- Intuitive way of working with a certified joystick.
- System placed in robot wrist.

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INTRODUCTION: *Certifications*

- ISO/TS 15066: Robots and robotic devices. Collaborative robots.

  Safety in collaborative robots and working environment.

- EN 1005-X: Safety of machinery. Human physical performance.

  Decrease risk of moving loads and reduce repetitive movements.

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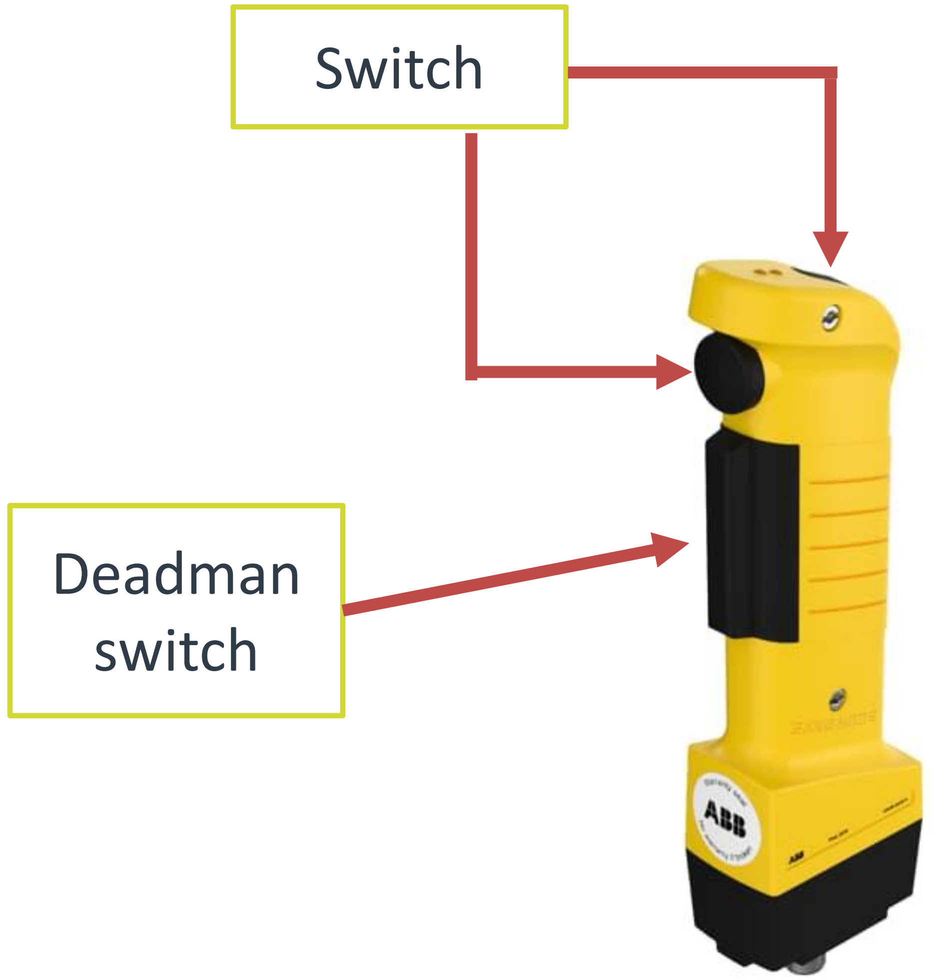
HARDWARE

Industrial robot

SCHUNK Force/Torque (F/T) sensor



Certified joystick

ABB JSHD4-2

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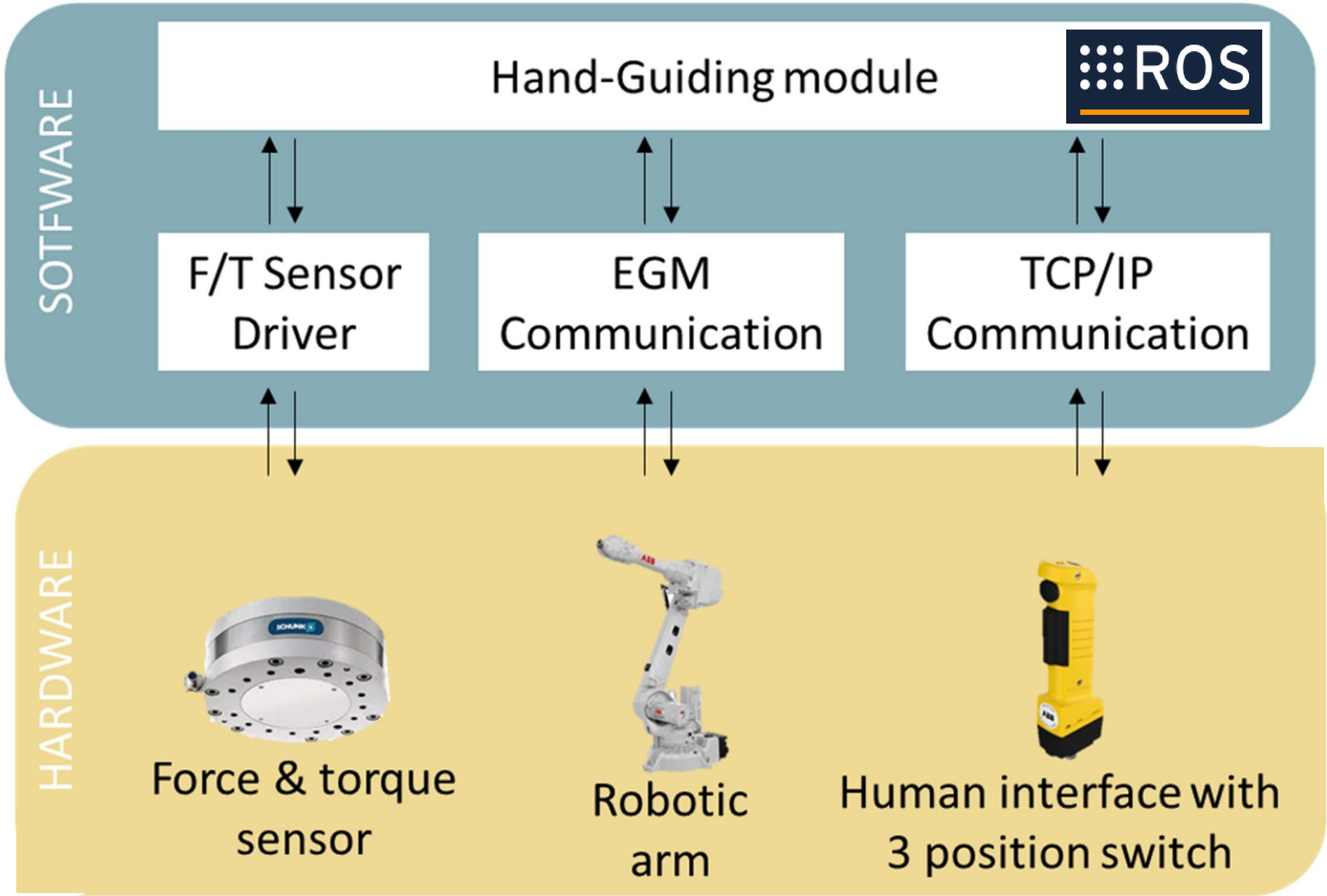
SOFTWARE

- HG Module to compute command based on force and robot position.

- High speed communication robot interface (~250 Hz):
  - ABB: External guided motion (EGM)
  - KUKA: Robot sensor interface (RSI)



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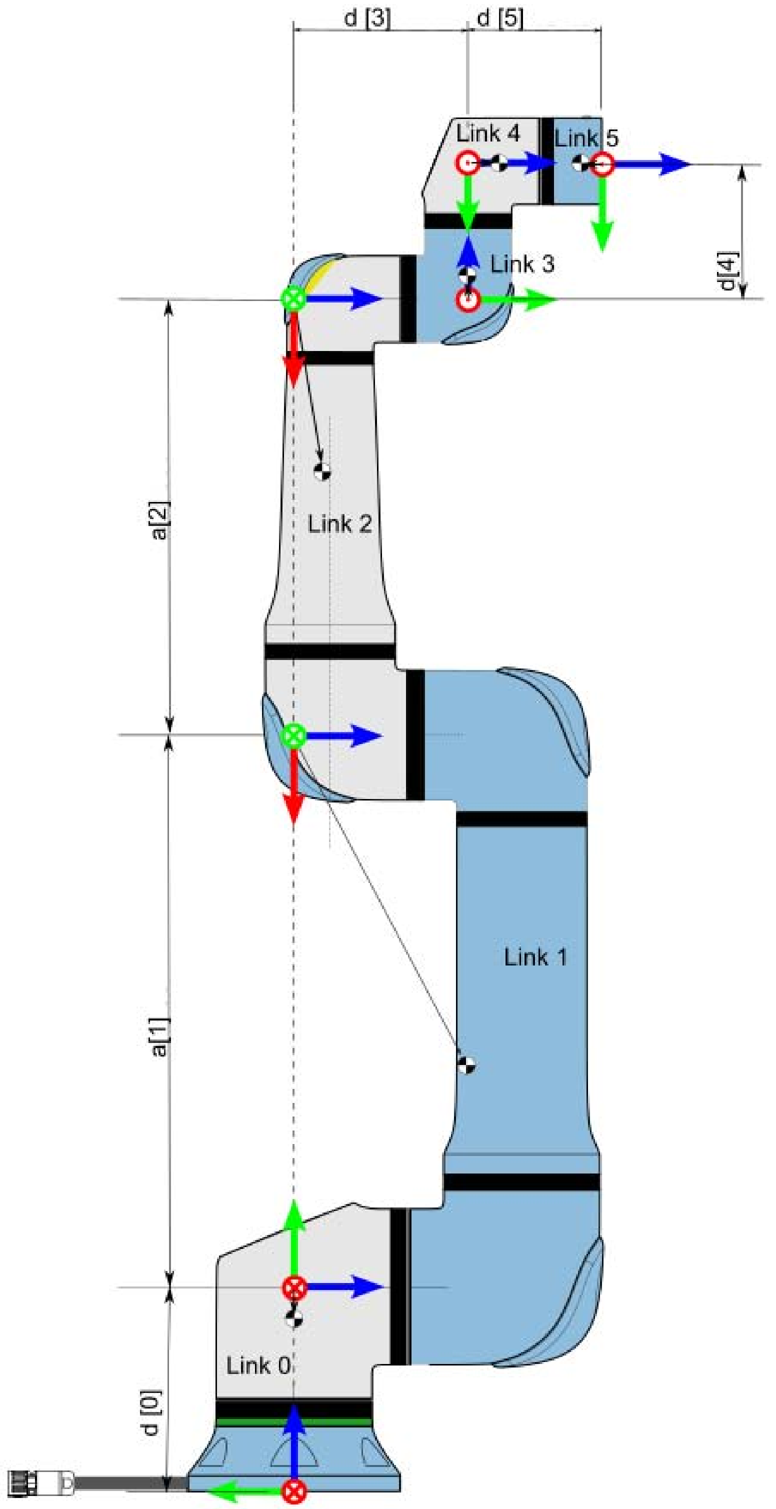
TECHNOLOGY DEPLOYMENT

Denavit Hartenberg (DH) parameters

- Obtain relative transforms between joints.
- Robot description represented with 4 parameters:
  - 2 rotations
  - 2 translations
- Consider sensor positioning.



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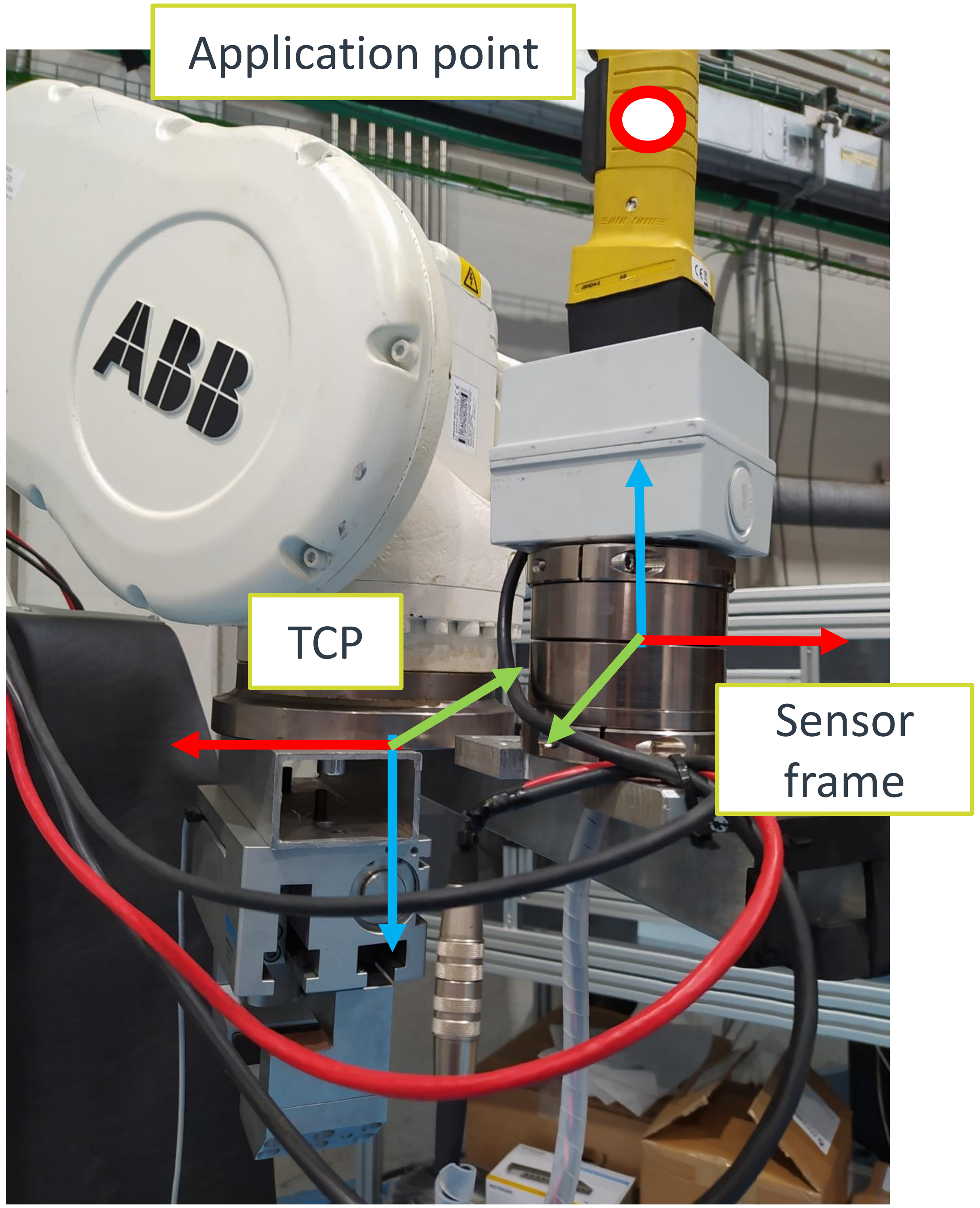
TECHNOLOGY DEPLOYMENT

F/T sensor placement and application point

- Consider distance and rotation to last robot joint.
- Compute application point.
- Used for computing correctly desired robot movement.



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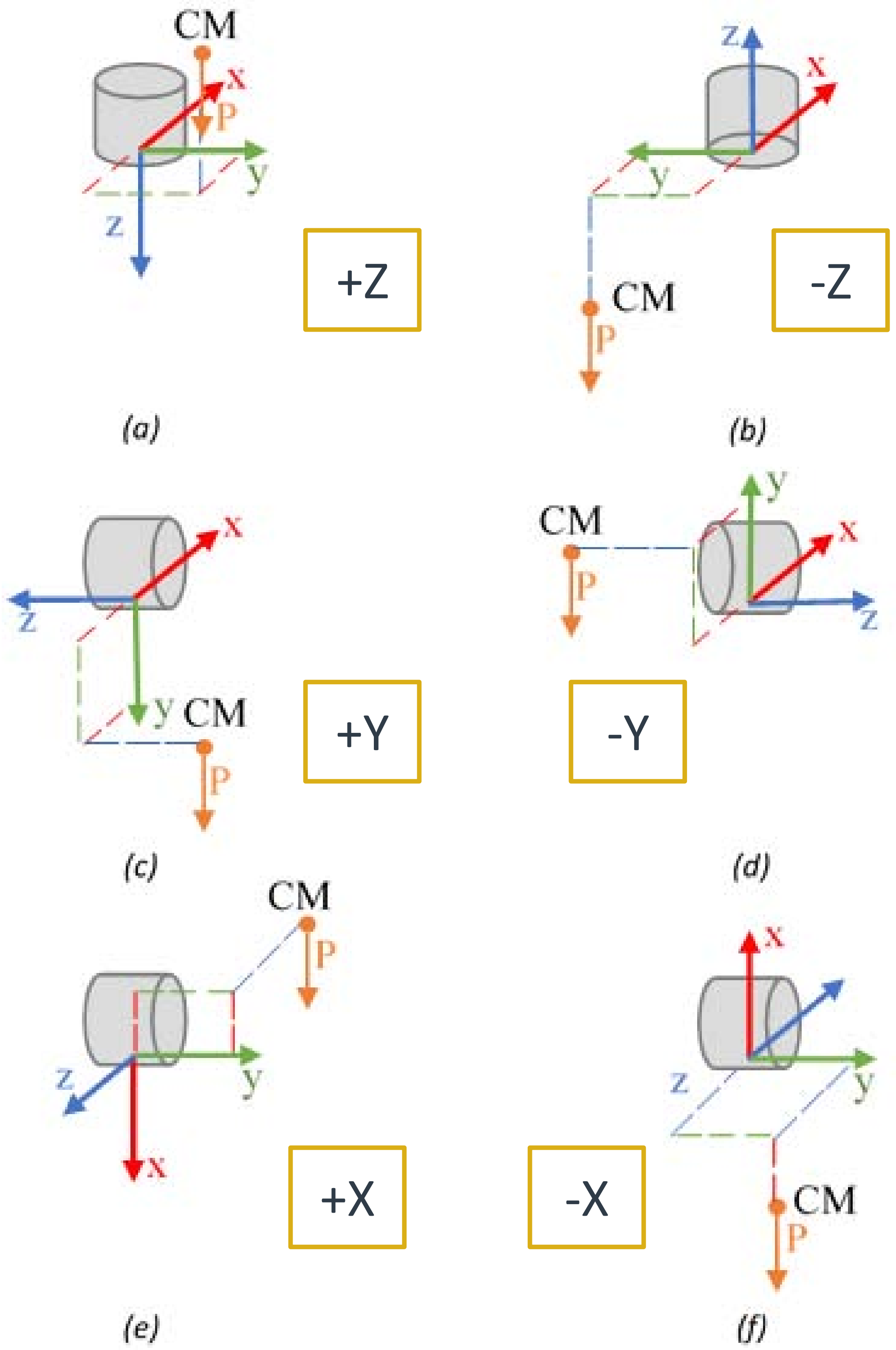
TECHNOLOGY DEPLOYMENT

Sensor calibration

- Process required to properly compute applied force on the sensor.
- Align each sensor axis (+/-) direction of gravity.
- Outputs weight, force and torque applied on the sensor.



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TECHNOLOGY DEPLOYMENT

Adjust controller response

- By modifying some parameters we can adjust:
  - *Weight of read F/T values*
  - *System inertia*: affects to start and finish robot movement
  - *System friction*: resistance during movement

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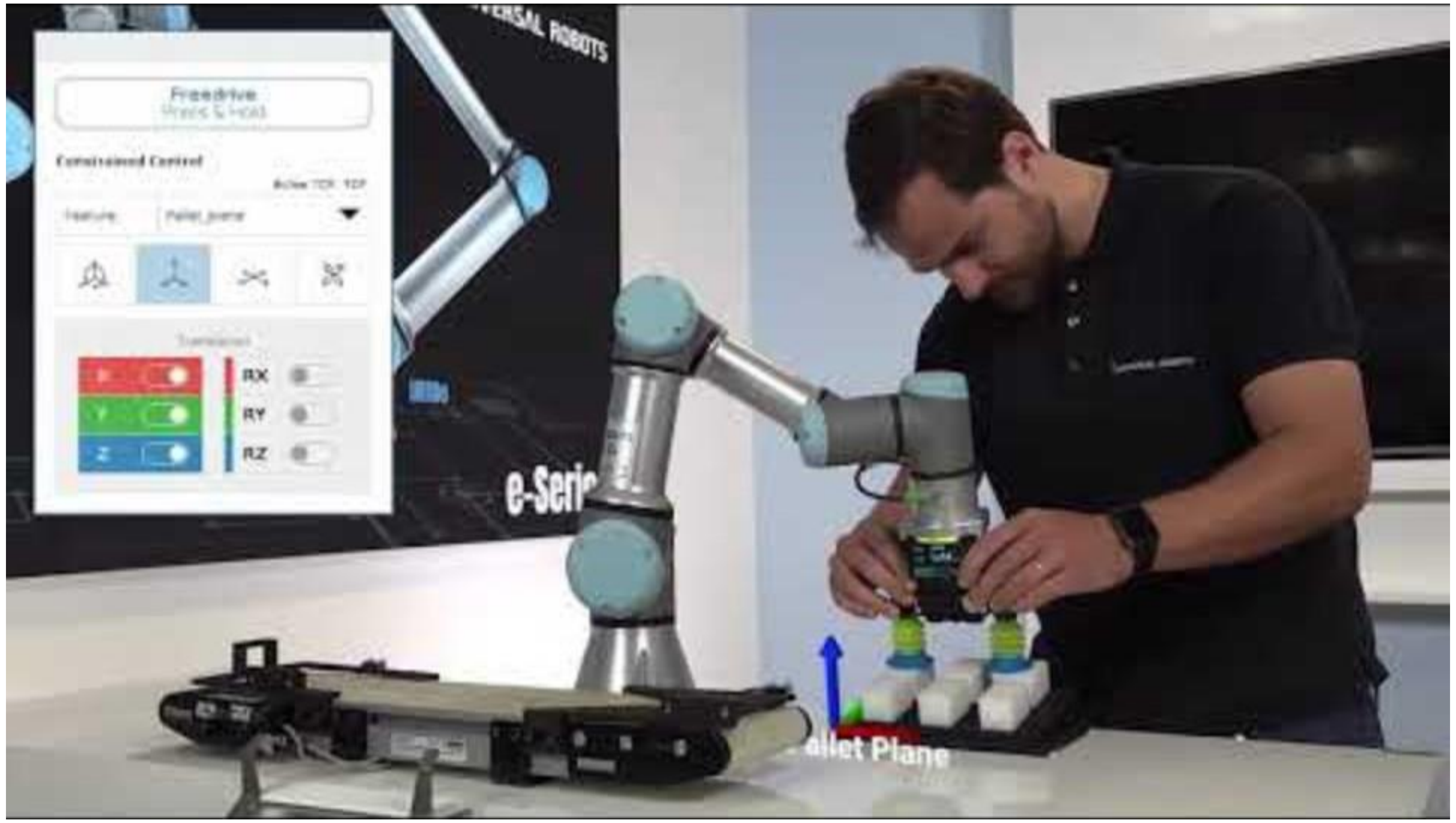
DEVELOPMENT: *Current solutions in the market*

Fanuc Collaborative robot

Source: Fanuc

Universal Robot (UR)



Source: Universal Robots Academy

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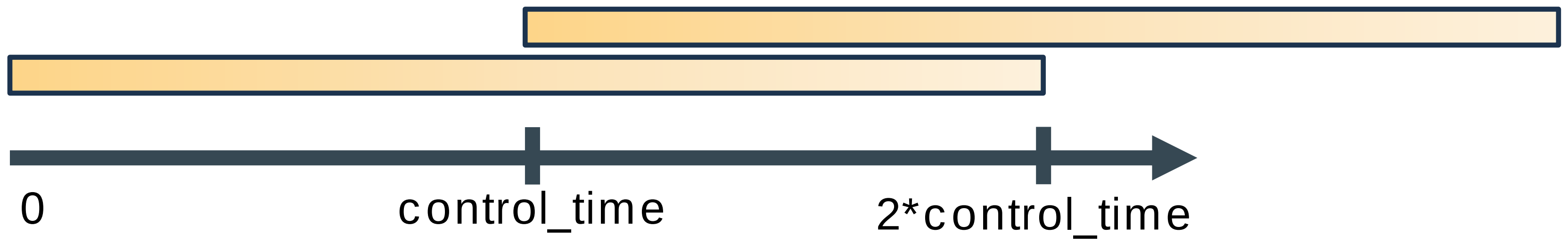
DEVELOPMENT: *Our solution*

ABB robot

- Velocity commanded
- Send directly extracted velocity from the controller

KUKA & COMAU robots

- Position commanded
- Requires additional computation to transform from velocity to position
- Time for computing higher tan commanded time



SMOOTH RESPONSE

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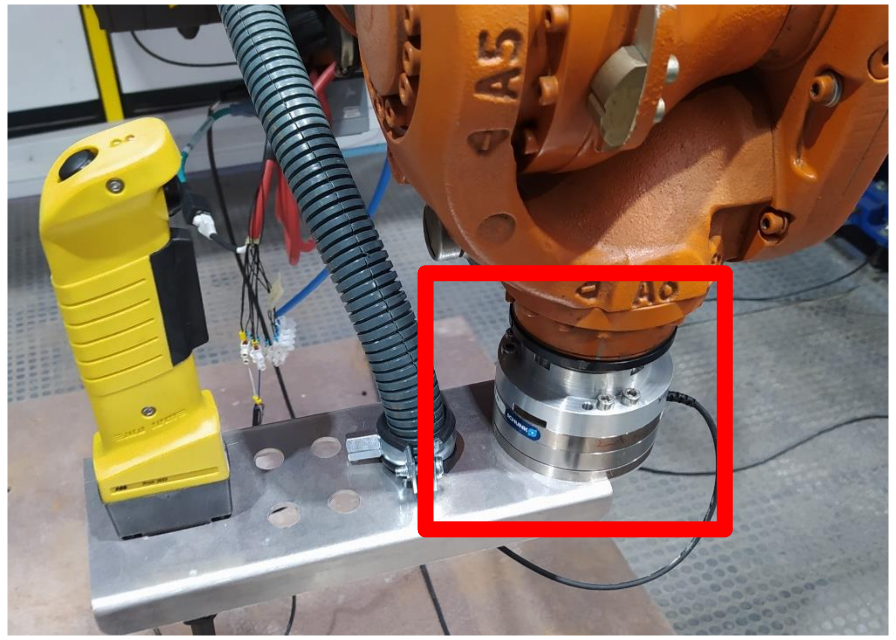
APPLICATIONS: LOADS HANDLING



KNOWN LOADS

- Load must be calibrated with the sensor.
- F/T sensor between tool and gripper.

UNKNOWN LOADS

- Sensor attached to joystick, externally to gripper.

ONLY HAND GUIDING MODULE IS REQUIRED

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APPLICATIONS: TRAJECTORY PROGRAMMING

Store point button

Modify accuracy

Deadman switch (only ABB)

In KUKA we use the teach pendant Deadman. This switch cannot be replaced by the joystick, only duplicated.

HAND GUIDING MODULE AND TRAJECTORY RECORDING MODULE REQUIRED

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DEMONSTRATION

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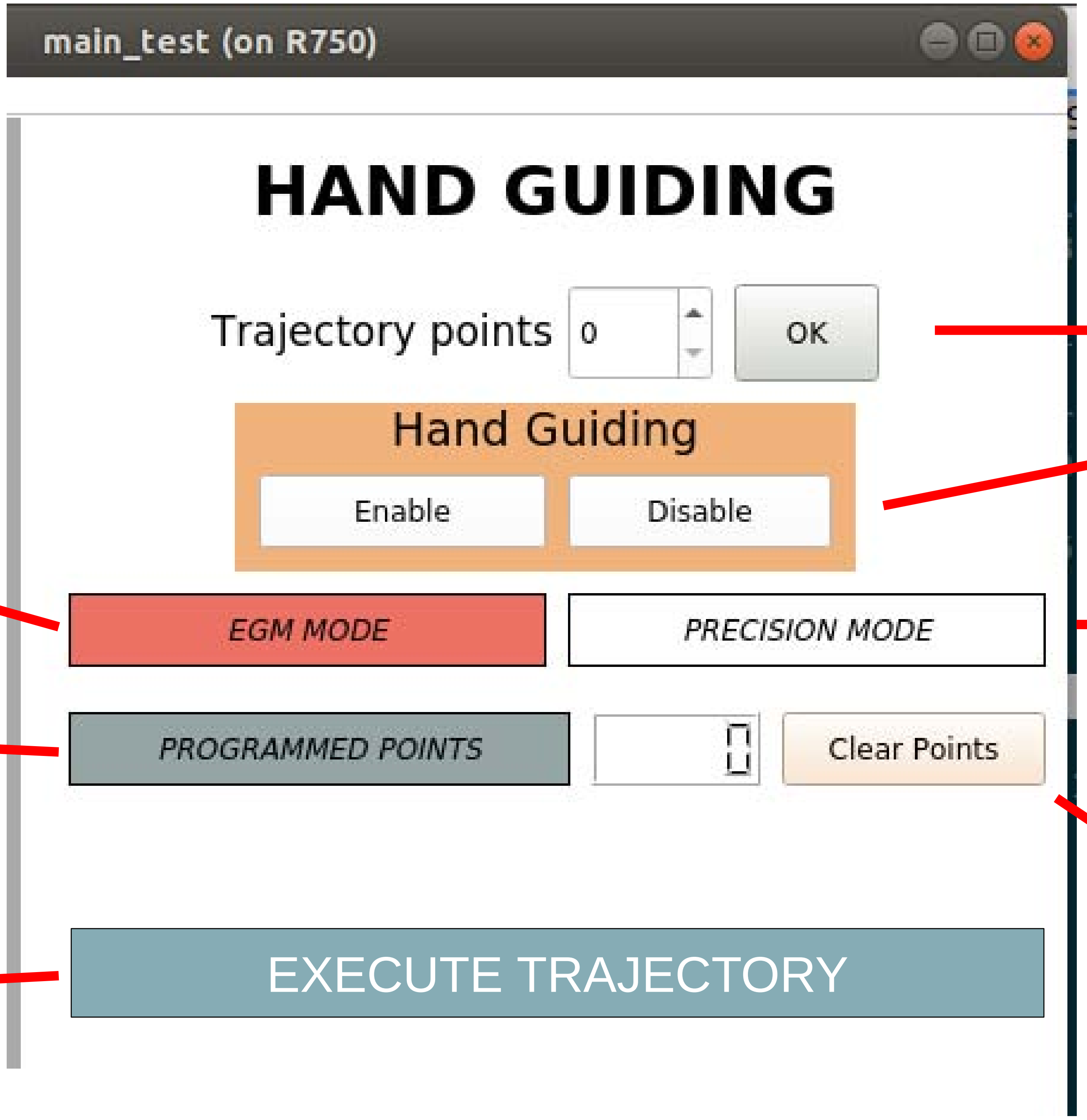
Graphical user interface (GUI)



Select total points

Enable / disable HG buttons

Visualization:
- EGM Mode (ON/OFF/Calib)

Visualization:
- PRECISION MODE (LOW/MEDIUM/HIGH Accuracy)

Visualization of total stored points

Clear stored points

Send and execute trajectory

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DEMONSTRATION

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DEMONSTRATION

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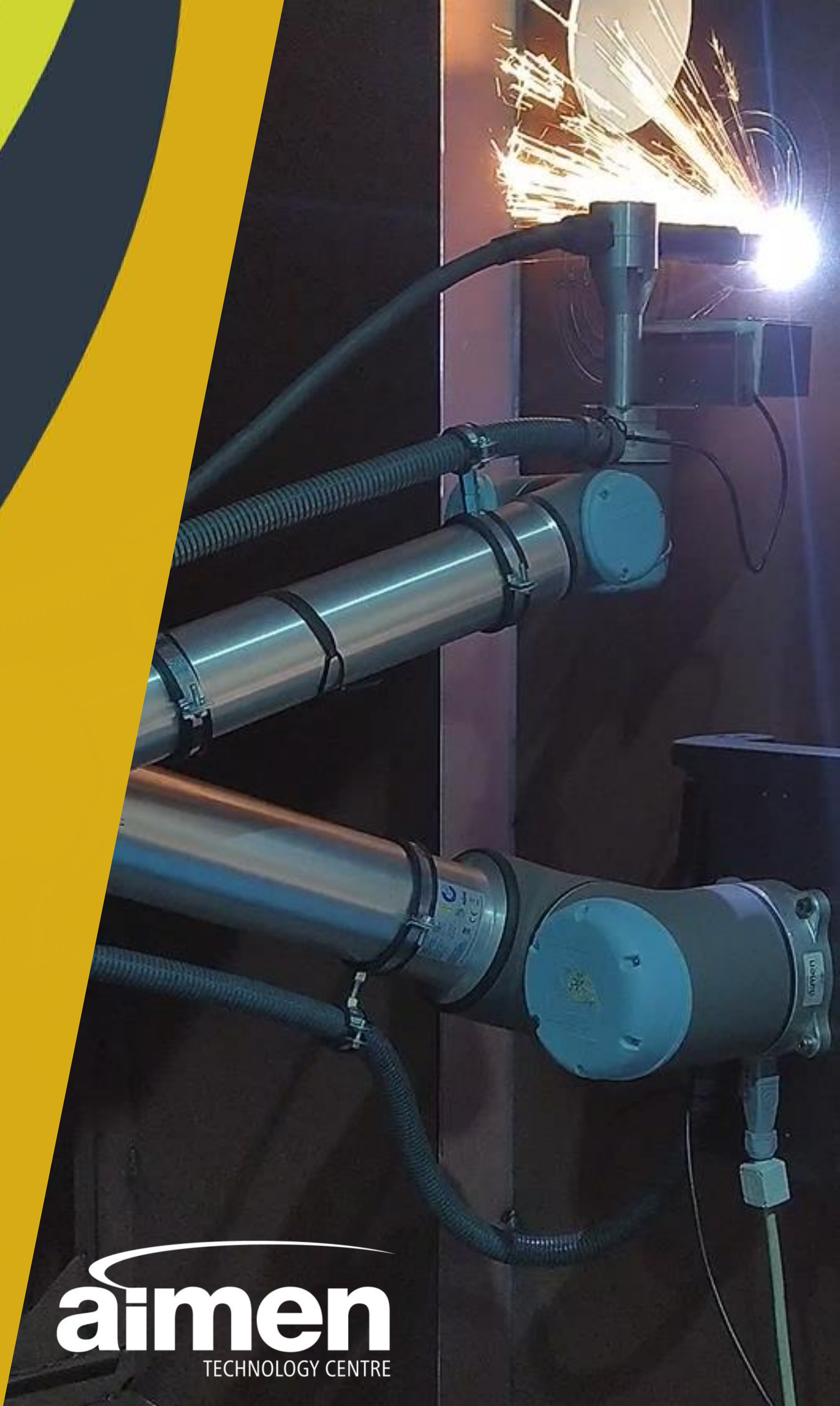
Collaborative robot for plasma-cut application (PFL)

Afra María Pertusa Llopis

O Porriño, 10th April 2024

These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.



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CONTENTS

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INTRODUCTION: Potential use-cases for collaborative robots

Manufacturing	Agri-food	Maintenance
Pick and place of manufacturing components	Pick and place of the agri-food	Teleoperations
Welding and gluing	Harvesting	Fastening and unfastening
Assembly of components	Order preparations	Teaching and skills
Quality check and inspection	Quality check and inspection	Quality check and inspection

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INTRODUCTION: Plasma cut application

- Application for plasma cut based on artificial vision and collaborative robots.
- Support in Naval Sector components manufacturing
  - Portable solution
  - Easy deployment with parametrisation
  - Hazardous environments and difficult access areas
  - Geometry adaption
- Application adaptable by changing robot tool.

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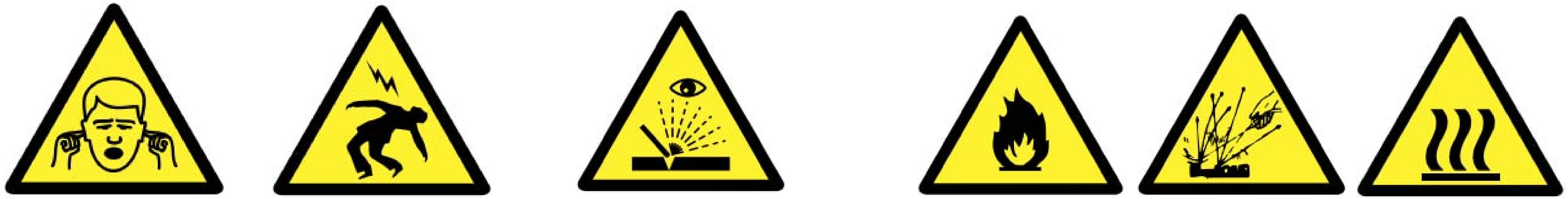
SAFETY ASPECTS

Cutting operations



Noise | Electrocution | Projections sparks | Fire and heat risk

Air quality, smoke and gases

EPI

Considerations

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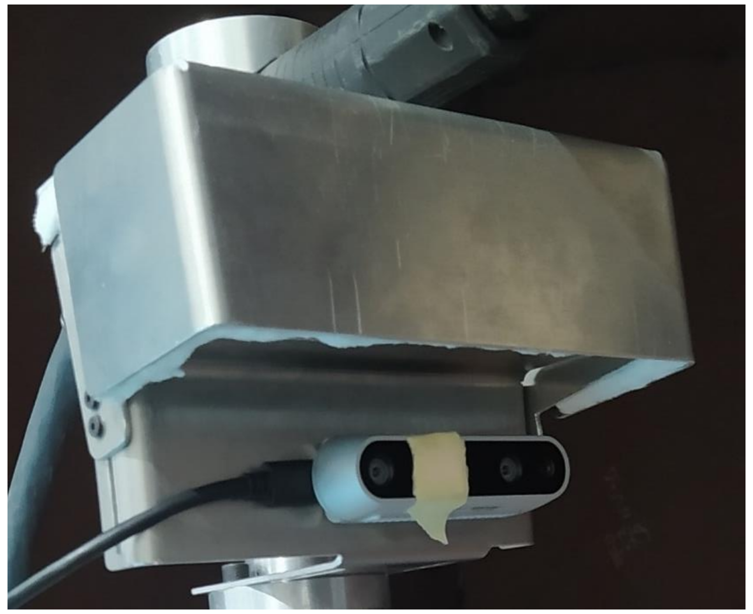
APPLICATION

Hardware



Camera support and lens protection

UR10

- Payload: 10kg
- Weight: ~30kg

Intel RealSense d435i

Range: [0,11-10] m

Accuracy: <2% in 2 n

Magswitch Cobot UR10

Weight: 30kg

Plasma power and torch

- Hypertherm Powermax 85
- Hypertherm Duramax Hyamp 180

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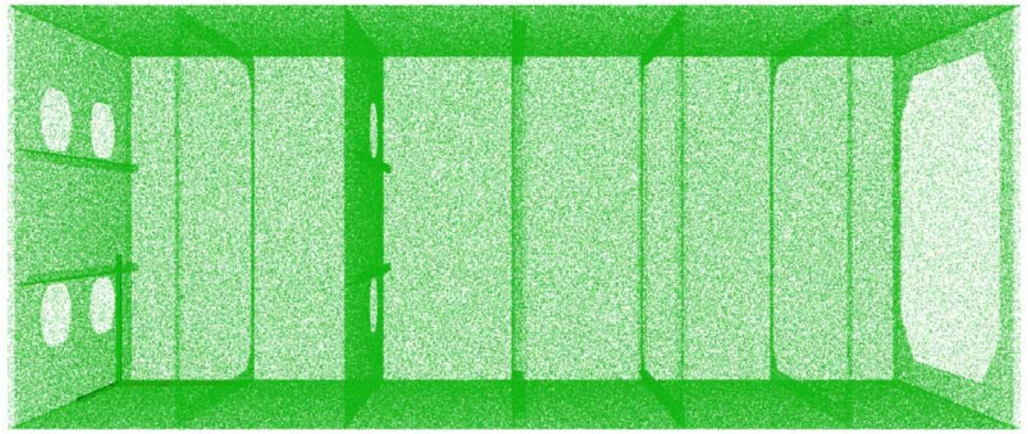
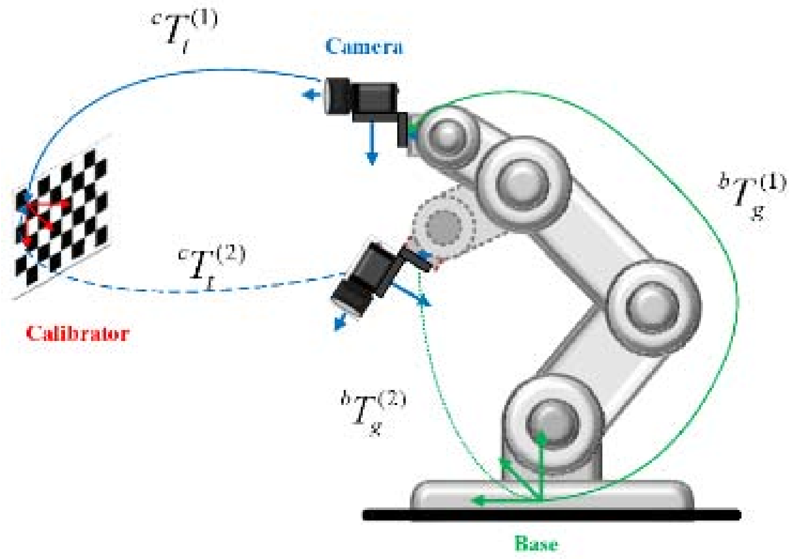
APPLICATION



CAD environment file

Software

- Requirements / Dependencies
  - Ubuntu 18 + ROS Melodic
  - Point Cloud Library (PCL1.8)
  - ROS Drivers:
    - RealSense ROS Driver
    - Universal Robots Driver
  - CAD and cut parameters
- Modules
  - Camera-robot calibration
  - Indoor localization module
  - Cut plane detection
  - Cut execution
  - GUI



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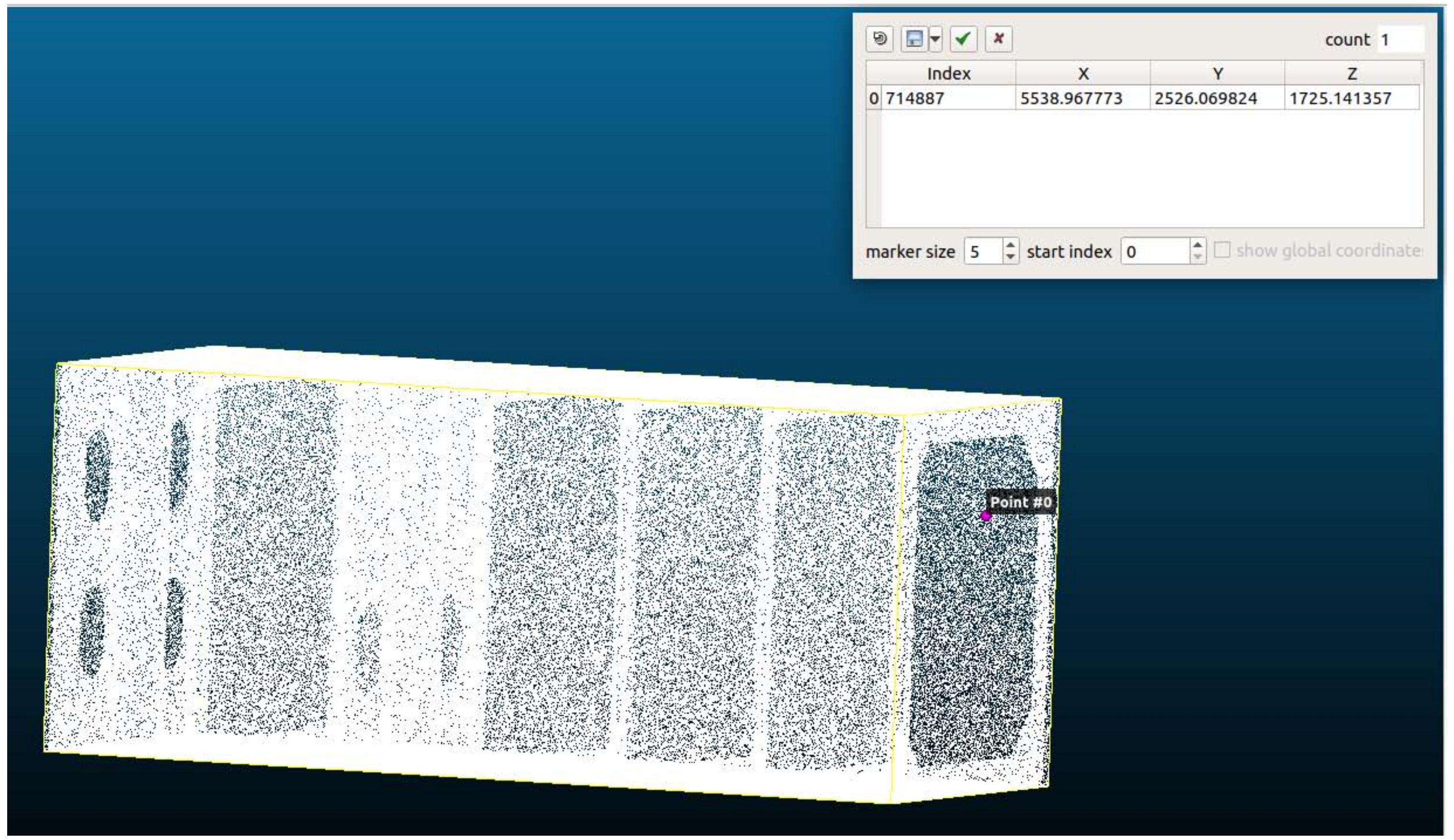
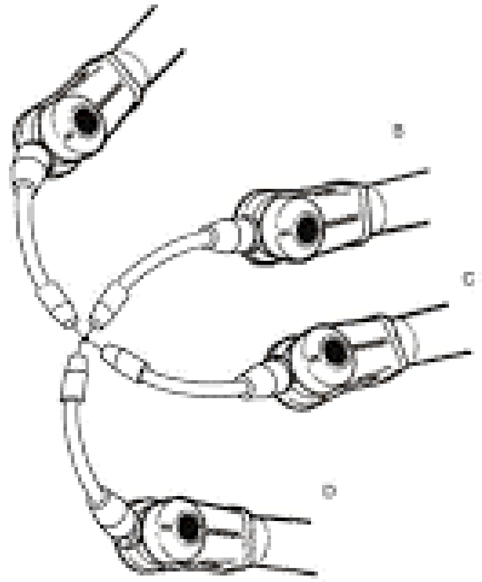
APPLICATION

Description

- *Offline sequence*
  - Camera-TCP calibration
  - TOOL Calibration: 4-points method with orientation
  - Hardware transportation and electrical connections
  - Cut centre point configuration (got directly from CAD file)





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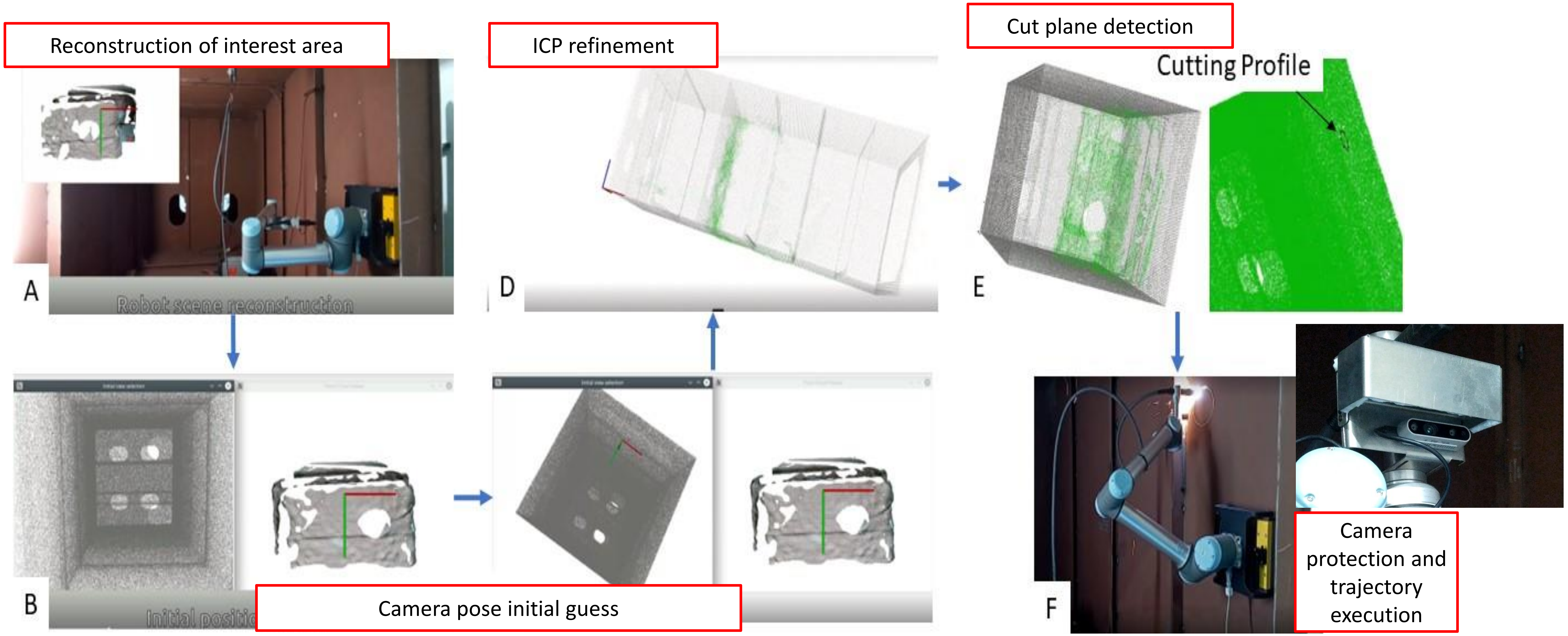
APPLICATION

- *Online sequence*



Masood et al. Green Manuf Open 2024;2:XXDOI: 10.20517/gmo.2023.102601

Sequence Execution and Control through ROS

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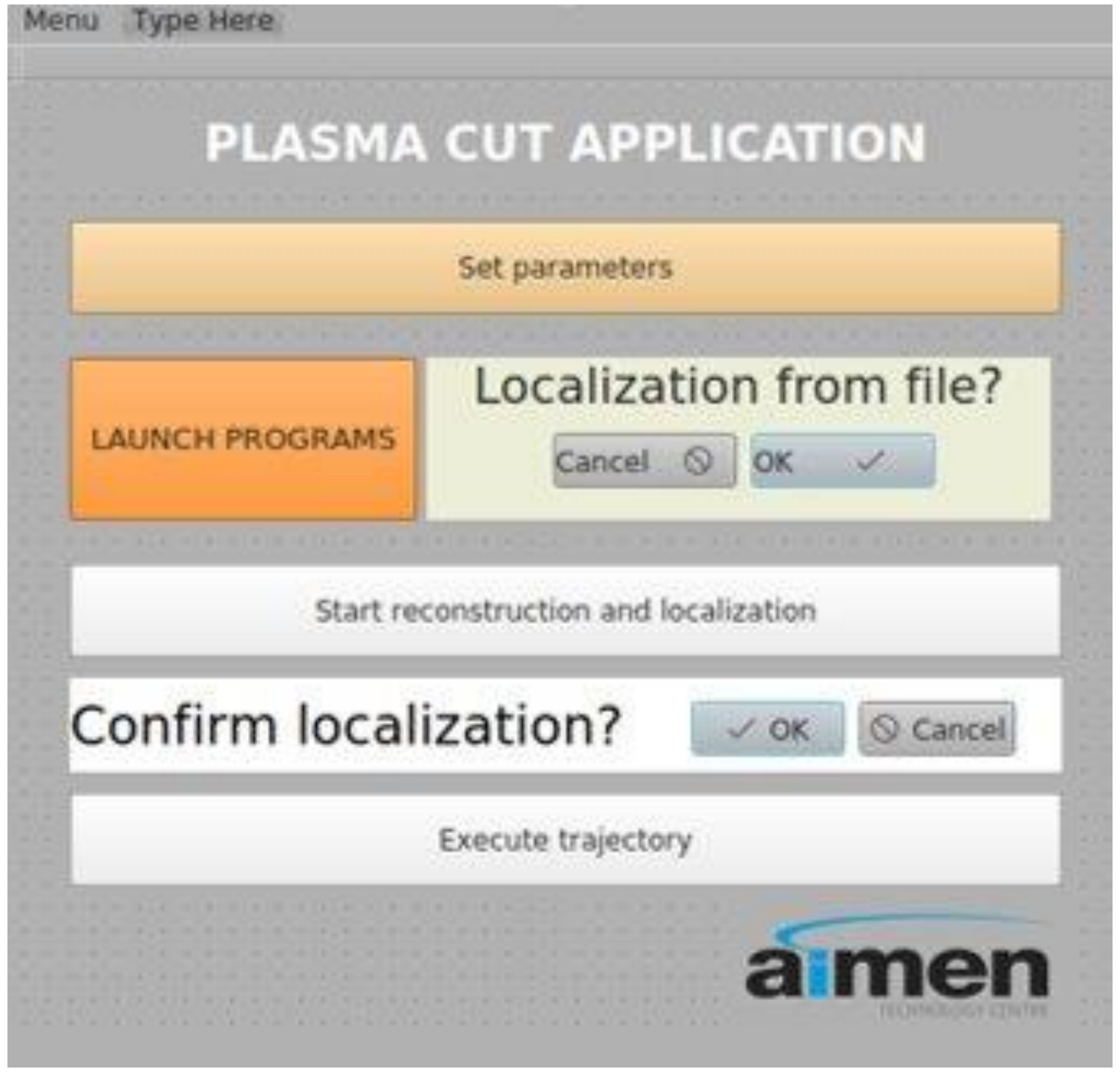
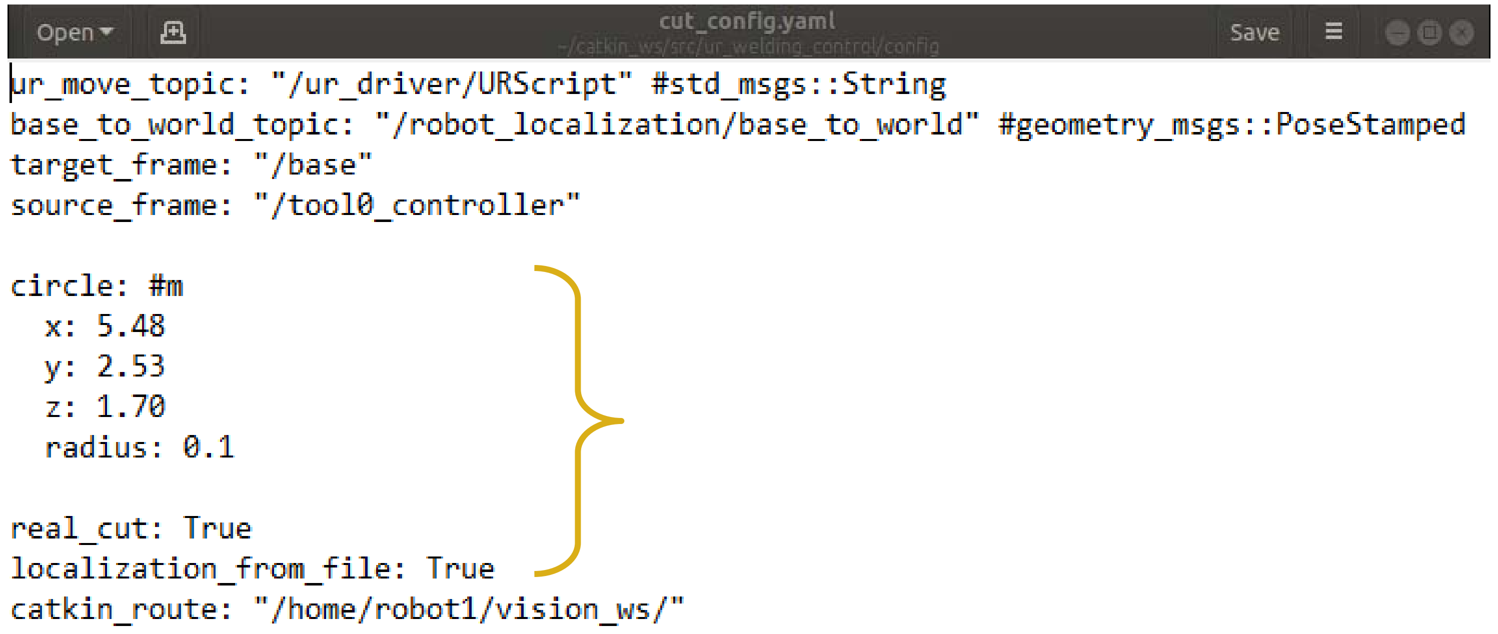
GRAPHICAL USER INTERFACE (GUI)






```yaml
ur_move_topic: "/ur_driver/URScript" #std_msgs::String
base_to_world_topic: "/robot_localization/base_to_world" #geometry_msgs::PoseStamped
target_frame: "/base"
source_frame: "/tool0_controller"

circle: #m
  x: 5.48
  y: 2.53
  z: 1.70
  radius: 0.1

real_cut: True
localization_from_file: True
catkin_route: "/home/robot1/vision_ws/"
```


These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798 and No 958303.

DEMONSTRATION

PeneloPe
CLOSED-LOOP DIGITAL PIPELINE
MARI4YARD
MARI4ALLIANCE

Robot and welding machine transport

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aimen
TECHNOLOGY CENTRE

DEMONSTRATION

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ROBOT LOCALIZATION AND PLASMA CUT

MARI4YARD
MARI4ALLIANCE

Collaborative & embodied robotics

Technological advances towards human centric industries

MARI4YARD
MARI4ALLIANCE

PeneloPe
CLOSED-LOOP DIGITAL PIPELINE

Instructor: Jawad Masood
What we have learned so far - RECAP

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Takehome message

Needs	Collaborative and Embodied Robotics Today
IMPACT	• Technology have shown the benefits but still need **drastic improvement** (Universal Robots, or similar) • Simple solutions are "**the best"**
RELEVANCE	• Technology is **up to the mark** in facilitating training and familiarity of use • Better **training tutorials** and product documentation can **improve** this criteria
UTILITY	• These devices are designed in keeping **one specific task** in mind however, in real world the worker is • performing **many sub-task** • Devices have shown the potential of **productivity improvement**
USABILITY	• There is a **gap between** industrial user requirements and today products • This gap **can be shorten** by constructive feedback
SAFETY	• The technology **need to focus** on the safety aspects • The objective of using such technology is to **improve** the safety of the worker • The device **must not introduce** another safety risk
COST	• Today products are **over priced** mainly because of the low production • It is recommended to **review** in comparison with the existing technologies
REACH	• There are **few** European technology providers • It is necessary for sustainability to have a **good product ecosystem** in Europe

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Thank you for your attention!

For other technology trainings:

Learning check - QUIZ time:

Your feedback is crucial for improving our courses. Please share your thoughts to help us succeed:

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