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**All-in-one middleware for industrial
human-robotic-interaction**

DELIVERABLE

D4.1 Requirements specifications for the TEF's illustrative Use Cases

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List of author(s), contributor(s) and reviewer(s)

Name	Partner	Contribution/Comment
Mireya de Diego	CAR	Main Editor
Francisco Meléndez	FF	Reviewer
Aníbal Reñones	CAR	Reviewer
Alissa Zacaria	INT	Reviewer
Angelo Iapichino	INT	Main Editor
Walter Quadrini	POL	Main Editor
Gizem Bozdemir	PAL	Main Editor
Séverim Lemaignan	PAL	Main Editor

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List of Acronyms

EC	European Commission
KOM	Kick Off meeting
GA	Grant Agreement
HRI	Human Robot Interaction
TEFs	Testing and Experimentation Facilities
ROS	Robot Operating System
WP	Work Package
MR	Mixed Reality
SSH	Social Sciences and Humanities
EC	European Commission
KOM	Kick Off meeting
GA	Grant Agreement
FSTP	Financial Support of Third Parties



● Executive Summary

This document D4.1 "Requirements specifications for the TEF's illustrative Use Cases" provides a detailed description of the requirements and specifications for the illustrative application and use cases within the ARISE project. The aim of the **illustrative use cases** is to propose realistic examples and its associated requirements analysis that later on in the project will serve as a source of inspiration for the applicants of the FSTP program. These use cases aim to demonstrate the applicability and functionality of the ARISE framework in various industrial settings. The document begins with an introduction that contextualizes the importance of formalizing the use cases in relation to the ARISE proposed challenges and establishes the purpose of the document. It then describes the methodology used to formalize the use cases, including iterative approaches and collaborative working sessions.

In the document we propose a use case table that plays a fundamental role in organizing and presenting the formalized use cases in a structured manner. It provides an overview of each use case, including its purpose, technical requirements, necessary hardware and software, as well as functional and non-functional requirements. Additionally, it details the outcomes of the working sessions and discussions related to the formalization of the use cases, highlighting key decisions made during the process.

In summary, the document D4.1 establishes a solid foundation for the works to be done in the project's testing and experimentation facilities (TEF) along the first year of the project that will arrive at an implementation and demonstration of the illustrative use cases within the ARISE project taking advantage of the proposed socio-technical framework for a better development of HRI applications. It provides a clear understanding of the requirements and specifications needed for each application case, enabling progress in the development and integration of the ARISE framework into real industrial environments.

1. Introduction

This deliverable D4.1 describes the details of the description of illustrative cases and requirements (technical, non-technical) for the framework that will be implemented as internal, long-term demonstrators and offered as an off-the-shelf asset to the experiments that will be developed in the FSTP's processes. This document provides a detailed exploration of illustrative examples and their accompanying descriptions and requirements by delineating the specifics examples of the challenges, it lays the groundwork for their successful implementation and integration within the project's Testing and Experimentation Facilities (TEFs).

1.1 Purpose and Scope

The purpose of this document is to establish a clear understanding of the use cases and their associated requirements and to provide comprehensive guidance for their development within the project's framework. Through a detailed examination of technical and non-technical prerequisites, this document aims to offer a roadmap for the realisation of Agile Human-Robot Interaction (HRI) across a spectrum of scenarios.

The scope of this deliverable, **D4.1** focuses on documenting the iterative process undertaken within the project, the identification and description of illustrative cases that exemplify the functionalities and capabilities of the ARISE framework. Additionally, it outlines the specific technical and non-technical requirements necessary to bring these illustrative cases to fruition within the project's TEFs. By elucidating these requirements, this document facilitates alignment with project objectives and ensures the successful implementation of the ARISE framework in real-world industrial environments.

Key steps in this process include:

- Refining the initial challenges to specific the users involved, main goals, course of actions, alternatives or situations of alternate course of events and identifying commonalities in journeys to create common course use cases.
- Selection of illustrative examples of the challenges to the human-robot interaction domain in the TEF's
- Analysing the examples of initial challenges, defining the main flow, extensions and capabilities relevant, providing the diagrams which shows the interactions of the identities involved in the use cases.
- Specifying a collection of use cases and the actor involved for each example of application case.
- Generating inspiring information for the applicants and their potential challenges in the initial stages of the FSTPs processes.

This document D4.1 captures the inspiring examples and feedback generated during the initial iteration of this process. The insights gained from this iteration are crucial for enhancing and optimising the challenges to effectively support external experiments in subsequent phases of the project. Through this documentation, the ARISE project aims to evolve its tools and facilities, enabling more effective solutions for industrial challenges through human-centric, AI-powered, and robotics-based automation solutions.

Link to relevant objectives and other tasks or deliverables.

Additionally, this document serves as a foundational piece connecting various objectives and tasks across multiple work packages (WPs) within the ARISE project.

- **WP4:** The outcomes of D4.1 lay the groundwork for T4.2- Initial TEF's set up, which focuses on the setup of Testing and Experimentation Facilities (TEFs). D4.1 will contribute essential insights that inform the establishment and operation of these facilities, ensuring their effectiveness in supporting experimentation and testing activities of the setup of these examples.
- **WP2:** The technical requirements specified in D4.1 inform the development and improvement of tools within WP2 of the ARISE project. By understanding the needs and challenges presented by illustrative use cases, WP2 can tailor its efforts to enhance existing tools or develop new ones that address specific requirements identified in D4.1. This alignment ensures that tools developed within WP2 are directly relevant and beneficial to the experimentation activities conducted in TEFs.
- **WP3:** D4.1 contributes to WP3's focus on human-centric aspects and ethical considerations within the ARISE project. By outlining the requirements of human-centric aspects for illustrative use cases, D4.1 ensures that experimentation activities conducted in TEFs are conducted in an ethically sound manner and prioritise human well-being, considering the SSH (Social Sciences and Humanities) framework. This alignment underscores the importance of considering social, ethical, and human-centric factors in the development and deployment of robotic solutions and their use cases within industrial contexts.
- **WP5:** This document serves as information to create the documentation for T5.1- Consultative process for challenges definition, mainly the information outline in the D5.1-Call Announcement and Guide for Applicants (phase 1) and also for T5.2- Expression-of-Interest [EoI] for a pool of use-cases in the initial phase of the FSTPs processes.
- **WP6:** This document, D4.1 establishes a connection with several objectives and tasks outlined within WP6 as such T6.1-FSTP Mentoring services- Experiments management and coordination, by providing clear guidance on the technical and non-technical aspects of illustrative use cases and T6.2- Individual Mentoring Plan for FSTP projects, by understanding the needs and challenges presented, enables mentors to tailor their support and guidance for applicants of the experiments.

1.2 Structure of this document

The structure employed in this document D4.1 follows a systematic approach to formalizing the use cases within the ARISE project. It begins with a formalization approach that outlines the process of defining and structuring the use cases. An iterative process is then adopted, which includes key components such as a Kick-off Meeting (KoM) interactive session, the development of a Use Cases Table, and workshops to refine and validate the use case details. This iterative approach ensures that the use cases are thoroughly analysed and accurately represent the objectives, requirements, and specifications about the individual capabilities of the examples outlined.



Challenges and Use Cases:

The document presents a comprehensive overview of the challenges addressed within the ARISE project, each accompanied by specific use cases. These challenges encompass a wide range of industrial scenarios, including dismantling and assembly of high-value products, complex product picking in warehouses, flexible collaborative robots, smart programming, enhancement of human-robot interaction (HRI) through multimodal interaction, fetch and carry tasks in healthcare environments, and improvement of worker efficiency and ergonomics in high precision tasks. For each challenge, corresponding use cases are detailed, providing specific application scenarios and objectives within the context of the ARISE project.

1.3 Contributions of the partners

The following table provides the main contribution from participant partners in the development of this deliverable:

PARTNER AND SHORT NAME	CONTRIBUTION
CARTIF (CAR) WP1, WP4 leader TEF1 owner	CARTIF is responsible for the overall coordination of the activities indicated in this document. CARTIF has established the overall structure of the document and completed all details concerning the methodology, technologies and framework for formalising the use cases. Also, CARTIF is responsible for the use cases of the Challenge 1 and Challenge 2.
FIWARE (FF) WP2, WP7 leader	FIWARE is responsible for the technical coordination, indicating the adequate methodology approach for the formalising of the use cases. This involves devising a systematic framework for defining and structuring the use cases within the project, ensuring their alignment to meet the specific requirements and objectives as outcomes for the WP2 in the development of the ARISE middleware.
DEMOS (DRI) WP3 leader	DEMOS is responsible for the WP3, SSH and Ethic framework. DEMOS has established the Human-centric aspect related to the use cases in the examples outlined in this document
INTELLIMECH (INT) WP6 leader TEF 2 owner	INTELLIMECH is responsible for the WP6 and also the use cases of the Challenge 3 and Challenge 4.
PAL Robotics (PAL) TEF 3 owner	PAL Robotics is responsible for the use cases of the Challenge 5 and Challenge 6.
POLIMI (POL) TEF 4 owner D4.2 leader	POLIMI is responsible for the T4.2 about the Setup of TEF's, and the deliverable related D4.2 and also the use cases of the Challenge 7 and Challenge 8.

Table 1. Contributions from partners.



2. Methodology

The ARISE project has an established list of major challenges which sets the direction of its innovation actions. This section outlines the structured approach adopted for formalizing a series of **illustrative use cases** and application cases which revolve around those challenges to help understand the scope.

- Each Illustrative Use Case or action of each actor/user focuses on one predefined challenge and shows a related industrial problem along with a human-centric and robotics-based solution.
- In turn, application cases or realistic examples of the challenge are specific instances or scenarios within each challenge area that exemplify real-world problems and potential solutions. These cases provide detailed insights into how the ARISE framework can be applied to address particular challenges faced by industries.

This methodology encompasses various techniques and frameworks to ensure the comprehensive and effective formalization of use cases. By detailing the chosen approach and overall process, providing insight into the methods employed to define, analyse and refine use cases. Through iterative processes, iterative sessions and workshops, the methodology aims to ensure alignment with project objectives, stakeholders need and industry best practices.

2.1 Formalization approach

For formalizing the following application examples, we adopted a structured approach that integrates elements of user-centered design and agile development methodologies to ensure relevance, feasibility and effectiveness. The first step is the analysis of the initial challenges using the following nomenclature as follows:

1. Identifying all **system users** and creating a role for each one. This step involves identifying and defining the roles of all users who interact with the system, each role is defined to outline the specific responsibilities and tasks.
2. Defining their **goals** and objectives are defined. This step involves understanding what each user aims to achieve or accomplish by interacting with the system, whether it is performing specific tasks, accessing certain information.
3. Describe the ideal/default **course of actions**, this involves mapping out the typical or expected sequence of actions that users will follow to achieve their goals within the system. It outlines the standard workflow or process flow that users will usually follow under normal circumstances to accomplish their tasks or objectives.
4. Defining illustrative **alternatives** or situations of alternate course of events. This step involves identifying potential deviations or exceptions from the idea/default course of action outlined in step (3). It considers alternative scenarios or edge cases where users may encounter obstacles, errors, or unexpected events that require a different course of action to be taken to achieve their goals.
5. Identifying **commonalities in journeys** to create common course use cases, common patterns or similarities in the user journeys identified in steps (1) to (4). These common user journeys represent typical scenarios that multiple users may encounter and each is described in details to understand the user experience and ensure that the system effectively supports their needs and goals.

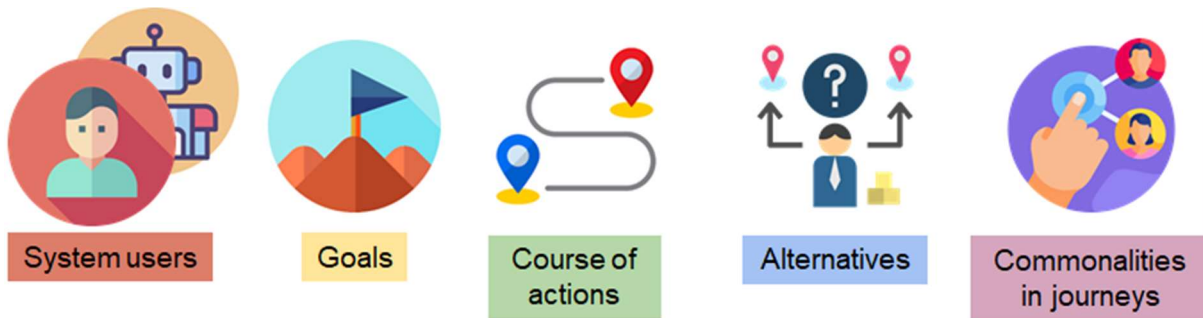


Figure 1. Nomenclature for the analysis of the initial challenges.

2.2 Iterative process

For formalizing the uses cases and application cases followed an iterative process, encompassing key steps and stages to ensure refinement. Initially, requirements gathering and analysis were conducted through stakeholder consultations and user interviews. This was followed by the creation of a draft use case table with the methodology to follow that was started in the ARISE’s proposal. The process included stages for review, validation and refinement to ensure alignment with the objectives of the project, partners and stakeholder needs. As references were included several examples in different scenarios such as manufacturing, logistics and healthcare.

2.2.1 KoM interactive session

During the Kick-off Meeting (KoM) hosted in CARTIF offices on January 23-24th, significant discussions, decisions and action plans were undertaken related to the formalization of use cases. Key topics included defining the scope and objectives of the formalization process, establishing timelines and objectives, assigning responsibilities to the project. partners. Decisions were made regarding the structure and format of the use case documents, ensuring consistency and clarity in the definitions. In the following figure is showed the distribution of the partners in the different teams for this interactive session, **TECH** mean technical issues related to the middleware, **SSH** the human-centric aspects, **FSTPs** issues related to the open calls processes and **KPIs** the potential indicators that will be improved in the TEFs. For writing down the issues related with these topics, post-it’s were distributed with this nomenclature and the partners had several rounds of the 10 minutes to discuss between dynamic teams and the different TEF stands about these issues, as represents the following figure:

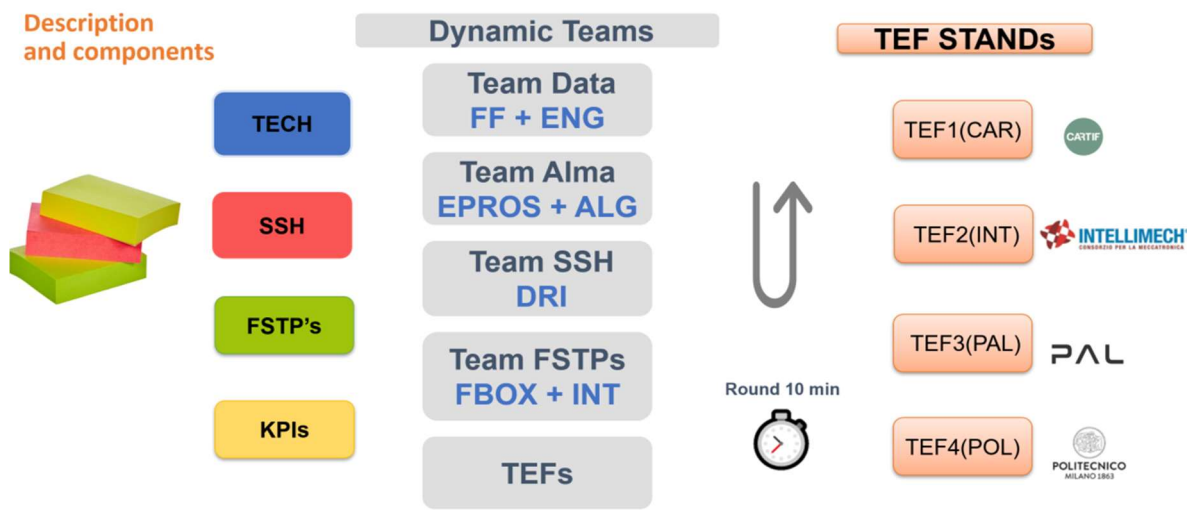


Figure 2.Slide for the interactive session with the partners.

The outcomes of the interactive session:

- TEF1 (CAR) focused on technical aspects such as connection OPC-UA, and latency, while the FSTPs prioritize specific challenges and key performance indicators (KPIs) related to flexibility of disassembly.
- TEF2 (INT) emphasizes the technical challenge of bridging ROS with ROS 2, with the solution being the use of Ros-bridge.
- TEF3 (PAL) highlights ethical considerations such as vulnerable end-user's views and processing personal data, alongside the alignment with ROS4HRI through a bottom-up approach. FSTPs aim to involve end-users and stakeholders in defining challenges, while the technical aspect questions if LLMs should apply in the challenges.
- Finally, TEF4 (POL) focuses on incorporating views from workers and end-users ethically. FSTPs prioritize mentoring and matchmaking between open calls and TEFs.

TEF1 (CAR)	TEF2(INT)	TEF3(PAL)	TEF4(POL)
Tech -CONNECTION USE-IO VERTICAL OPC-UA -LATENCY FSTPs - SPECIFIC CHALLENGES KPI - FLEXIBILITY OF DISASSEMBLY	Tech -HOW TO BRIDGE ROS WITH ROS 2 -Solution → Ros-bridge	Ethics -Vulnerable End-users views -Processing Personal data Eprosimia align with ROS4HRI -bottom-up approach FSTPS -To involve end-user and stakeholders in the definition Tech -LLMs should apply challenges?	Ethics -How to incorporate views from workers & end-users FSTPS Mentoring Matchmaking open call&TEF

Figure 3.Outcomes obtained in this interactive session.

2.2.2 Use Cases Table

The use case table serves as a central organizing tool for presenting formalized use cases, providing structure, content and purpose. This structured format enables to easily comprehend the objectives, requirements and specifications of each use case in a standardized manner per application case. It includes the following structure:

- **Introduction & Purpose:** A concise overview of the purpose and significance within the ARISE project, outlining its relevance to project objectives.
- **Technical requirements:** Detailing the technical requirements for implementing the use case, including hardware, software and communication infrastructure.
- **Hardware:** Encompassing a comprehensive list and description of the hardware components indispensable for supporting the use case's functionalities, along with their specification and integration considerations.
- **Software:** Outlining the requisite software components, platforms, frameworks and tools necessary to enable the use case's functionalities, including any dependencies or compatibility constraints.
- **Communication:** Describing the communication protocols, interfaces and data exchange mechanisms utilized within the context of the use cases, addressing both intra-system and inter-system communication requirements.
- **Use Cases:** Presenting specific scenarios or workflows associated with the use case, delineating the sequence of actions, events or interactions entailed in its execution.
- **Functional Requirements:** Specifying the functional capabilities and features that the system must exhibit to fulfil the use cases' objectives effectively, outlining desired behaviours and functionalities,
- **Non-functional Requirements:** Documenting the non-functional aspects associated with the use case, such as performance, reliability, security and usability requirements, ensuring the system's adherence to quality attributes and constraints.

2.2.3 Use case Workshops

These workshops were conducted to facilitate the formalization process, aiming to engage project partners and stakeholders actively. The main objectives of these sessions included refining use case details, validating requirements, and addressing any inconsistencies. Outcomes of the workshop included finalized use case documents, clarified requirements and enhanced alignment with project goals.

- **1st Workshop - Examples per each initial challenge**

During the first workshop, the focus was on developing the first application case per initial challenge outlined in the project. Firstly, the TEF's owners introduced their application cases through the presentations and videos following with the involved brainstorming sessions, discussions and collaborative efforts to outline the main objectives, identify key actors and their roles, define the main flow of activities, and anticipate potential extensions or variations. The outcome of this workshop was the initial draft of the use case documents for each application case, laying the foundation for further refinement and development.

- **2nd Workshop -New examples for each initial challenge**

In the second workshop, the emphasis shifted towards generating new application cases to expand the scope and diversity of use cases within the project. Building upon the insights gained from the first workshop, participants worked collaboratively to identify new scenarios, challenges and opportunities



that could be addressed through additional cases. The outcomes of this workshop included the identification of new use scenarios, the refinement of requirements and the validation of use case details to ensure coherence and alignment across the project.

3. Challenges and their examples of application

This section describes specific examples of the initial challenges of the TEF's in the proposal. For this section is necessary the descriptions of the application cases with the specific nomenclature that is described as follows:

- **Description and main objectives:** this section provides a brief overview of each application case and outlines the main objectives or goals that the case aims to achieve, providing a clear understanding of its purpose and significance of the benefits within the project.
- **Actor:** refer to the individuals or entities that interact with the system being described. This section identifies the key actors involved in the sub-challenge, specifying their roles and responsibilities in relation to the use case. It clarifies who is involved in the process and what their specific contributions or actions are.
- **Main Flow:** Activities or processes associated, highlighting key steps or stages. The main flow outlines the sequence of activities or processes that occur within the application case under normal conditions. It describes the primary steps or stages involved in achieving the main objectives of the case, key actions or events that occur along the way.
- **Extensions:** Potential variations to the main flow that may occur under certain conditions or scenarios. Extensions describe deviations or alternative paths that may occur during the execution of the main flow. This section identifies potential variations or exceptions to the normal sequence of events, outlining how the system responds to these deviations to ensure the desired outcome is still achieved.
- **Main Capabilities:** This section identifies the main capabilities or functionalities required to support the use case. It specifies the key outcomes or objectives that the use case aims to achieve, highlighting the importance of capabilities related to perception, human-robot interaction (HRI), cognition, navigation and other relevant areas. These capabilities are essential for the successful execution of the use case and contribute to its overall effectiveness and efficiency.

3.1 Challenge 1- Dismantling and assembly of high-value products (CAR)

The challenge entails developing an industrial Human-Robot Interaction (HRI) solution to enable collaborative work between robots and human workers in dismantling and assembling high-value products. The solution aims to automate tasks, enhance efficiency, mitigate risks associated with hazardous materials handling and accommodate secondary processes, ultimately ensuring worker safety and improving overall productivity in the working environment. In the following table can see the application of the methodology identifying each part:

System Users	<ul style="list-style-type: none"> • Robots, human workers, acoustic and luminous response devices, cameras, computer system operators
Goals	<ul style="list-style-type: none"> • Work collaboratively: Enhance cooperation and interaction between robots and human workers to achieve efficient disassembly.



	<ul style="list-style-type: none"> • Increase efficiency: Streamline the process to reduce time and resource consumption. • Reduce the risk of injury or accidents: minimize the potential for harm to human workers or damage to equipment during the process. • Improve overall productivity: Enhance the output or yield of the disassembly process while maintaining quality standards. • Development of a multimodal system: Implement a system that integrates multiple modes of communication and interaction, such as voice commands, gestures and visual feedback. • Disassembly of mechanical joint components
Course taken	<ul style="list-style-type: none"> • Automate certain tasks: Implement automation to handle repetitive or labour-intensive aspects of the disassembly process • Tasks that require dismantling or assembly operations, depending on the specific components being processed.
Alternatives course	<ul style="list-style-type: none"> • Hazardous materials or components: handle potentially or sensitive materials or components with specialized protocols and safety measures. • Specialized handling: Implement specific procedures or techniques for the safe and proper handling of delicate or complex components. • Secondary processes: such as inspection or quality control, integrate additional steps beyond basic disassembly to ensure product quality and compliance with standards.
Commonalities in journeys	<ul style="list-style-type: none"> • Shared working environment: collaborative disassembly takes place in a shared workplace where robots and human workers interact. • High variability of products: Encounter a wide range of product types, sizes and configurations during the disassembly process. • Human judgment and expertise: leverage the knowledge and skills of human workers to make informed decisions or adjustments during disassembly tasks. • Worker safety: Prioritize the safety and well-being of human workers by implementing measures to prevent accidents or injuries in the disassembly environment.

Table 1. Analysis of the Challenge 1.

3.1.1 Example: Battery Disassembly

The primary objective is to optimize and expedite the disassembling process of batteries by utilizing a collaborative approach between humans and robots. This strategy integrates mixed reality and artificial vision technologies to accurately detect and localize screws within the battery, enhancing efficiency and accelerating the disassembly procedure.

Actors: Human workers, PC (System), camera, Robot and MR HoloLens glasses



The key actors involved in this application cases : (1) Human workers are tasked with supervising the disassembly process, establishing the framework and making critical decisions, such as selecting screws to retrieve, (2) The PC (System) plays a central role in calculating and transforming coordinates, coordinating robot actions and relaying data to the AR glasses for an enriched visual experiences, (3) Dimensional camera and (4) the collaborative robot work in tandem to provide accurate data and perform physical actions, respectively, while the (5) MR HoloLens glasses offer real-time visual information and track user interactions for an immersive user experience.

Main Flow:

The process commences with the dimensional camera, capturing both BGR and depth images of the object, and forwarding them to the PC for analysis. On the PC, coordinate calculation and transformation to both robot reference space and world coordinates take place. These coordinates are then relayed to the robot for precise guidance to the user. Moreover, the PC oversees the interaction between the robot and the human worker, converts text into audio and manages events, such as adjusting the colour of the table lights. Meanwhile, the collaborative robot selects screws for the disassembly process, facilitating smooth and efficient operation.

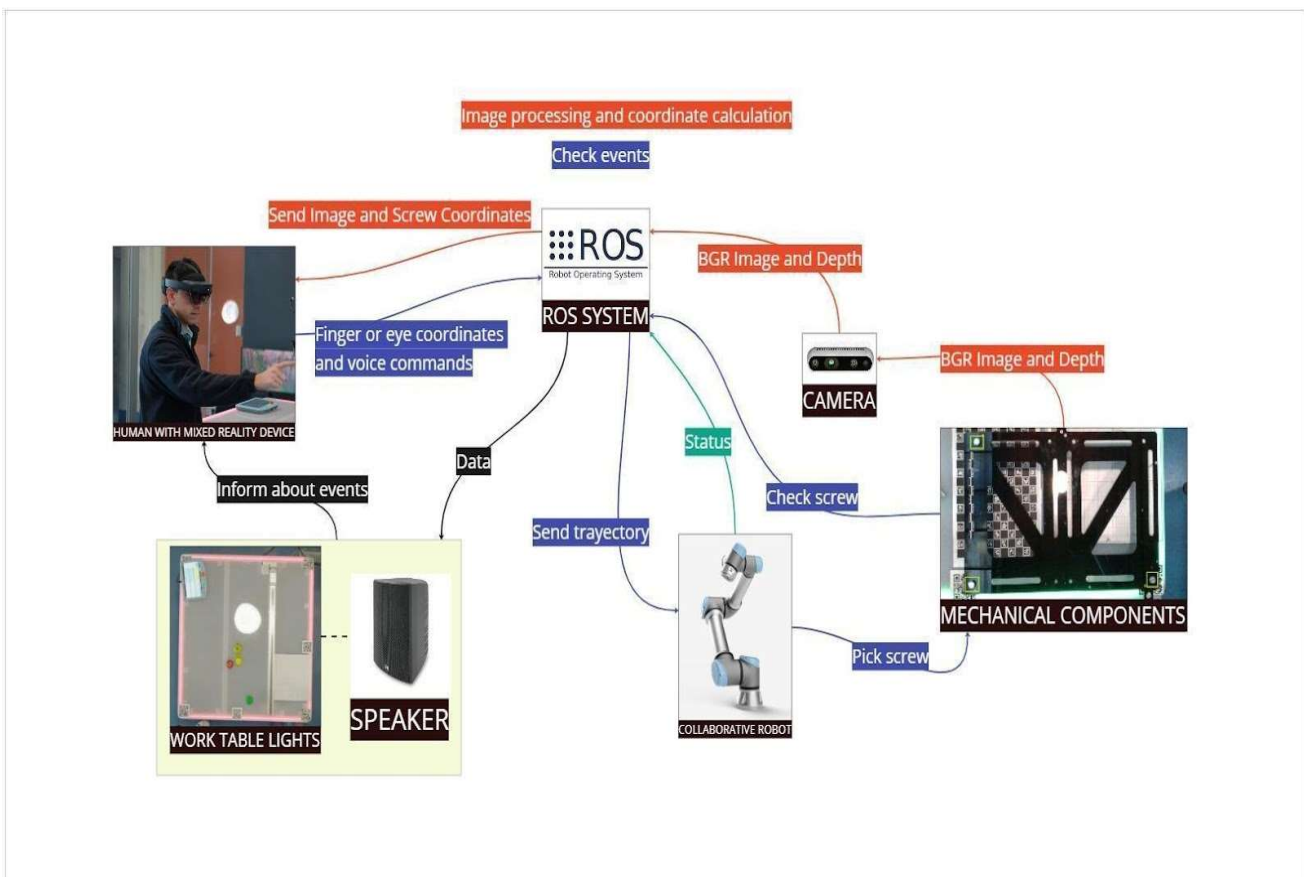


Figure 4. Main Flow of the Battery Disassembly.

Main capabilities

Considering the actor sequence and functional requirements, the target/main capabilities needed for the system will be:

- **Real-Time 3D Object perception:** the system should be able to localize objects in real time and accurately determine their 3D coordinates, which are relevant to the robot's task.

- **Mixed Reality Integration:** The system needs to integrate with mixed reality glasses to superimpose the 3D coordinates of identified objects onto the user's first-person view, enhancing situational awareness and facilitating interaction.
- **Voice Command Recognition:** The integration system should possess robust voice recognition, achieving a high accuracy in this type of interactions.
- **Robot coordination:** the system must be capable of sending the 3D coordinates of identified objects to the robot in real time to guide its actions effectively.
- **SSH / Human centricity context:** The applications raises questions of data protection and privacy if the cameras will be collecting and processes data that would make it possible to identify the human they are working with. the system must therefore consider the principles of privacy-by-design (e.g. blur the faces of the co-worker). We must also be mindful of long-term effects such as machine bias. We must be mindful of what the effects of these technologies are in the short term, but also what type of future they will create in the longer term. This raises questions of, for instance, job replacement. There might also be issues with human autonomy that we must explore.

3.2 Challenge 2- Complex Product Picking in industrial warehouses (CAR)

The challenge aims to develop a Human-Robot Interaction (HRI) solution for product picking in industrial warehouses. It seeks to overcome limitations of manual methods and traditional robots by integrating collaborative robots into the process. The key is ensuring the seamless collaboration between humans and robots, prioritizing worker safety while maximizing efficiency in product picking. The solution must also adapt to the high variability in shapes and weights of products, as well as handle purchase orders from IT systems. In summary, the focus is on improving human-robot interaction to optimize product picking operations in industrial warehouses.

System Users	<ul style="list-style-type: none"> • Robots, forklifts, workers, IT system operators
Goals	<ul style="list-style-type: none"> • Efficient picking of products: Streamline the product picking process to minimize time and resource consumption. • Ensure worker safety: Implement measures to protect workers from potential hazards or accidents during picking operations. • Maximize efficiency and minimize errors: Optimize the picking process to improve productivity and accuracy in product selection and handling
Course taken	<ul style="list-style-type: none"> • Integration of collaborative robots or forklifts for depalletizing: Incorporate collaborative robots or forklifts into the picking process to enhance efficiency and flexibility. • Launch of purchase orders from IT systems: Integrate IT systems to automate the generation and processing of purchase orders for efficient inventory management.

<p>Alternatives course</p>	<ul style="list-style-type: none"> • High variability of shapes and weights of packages: Address the challenge posed by the diverse range of product shapes and weights encountered in warehouse environments. • Space and geometry restrictions in traditional industrial robots: Overcome limitations associated with traditional industrial robots, such as spatial constraints and limited manoeuvrability.
<p>Commonalities in journeys</p>	<ul style="list-style-type: none"> • Handling objects with highly variable shapes and materials: Adapt picking processes to accommodate the diverse range of products stored in the warehouse. • Ensuring worker safety: Prioritize safety measures to protect workers from potential risks or injuries during picking operations. • Maximizing efficiency and reducing errors in the picking process: Implement strategies to optimize productivity and accuracy in the picking process, ultimately improving overall warehouse operations.

Table 2. Analysis of the Challenge 2.

3.2.1 Example: Fruit Picking

The main purpose is to make certain tasks that would be done by a human worker, like picking fruits, can be done by a collaborative robot, making the human-robot interaction possible and perform the work more efficiently.

Actors: Human workers, MR HoloLens glasses, system, collaborative robot and camera

The key actors involved in this application cases : (1) Human workers supervise operations and provide instructions to the collaborative robot via MR HoloLens glasses, (2) this glasses interface between human workers and (4) system, receive instruction, provide real-time visual feedback, (5) Collaborative robot executes tasks like sorting based on instructions from human workers and (6) camera captures visual data for object recognition and situational awareness, aiding decision-making in the system. The location of objects is represented as a digital sphere on the HoloLens 2 lenses so that the user is aware of the pick-up position of the collaborative robot.

Main Flow

The users engage with the mixed reality glasses through intuitive gestures, voice commands and gaze. The MR glasses relay this input to the user by providing a live camera view, object information and system feedback. Subsequently, the glasses transmit relevant data to the PC via Wi-Fi connection using WebSockets protocol. This data, formatted in ROS (Robot Operating System) format, is then processed by the PC and relayed back to the user. The PC serves as a central hub, facilitating communication between the user, glasses and robot, sending commands to the robot to perform tasks based on the user's input. In return, the robot provides updates on its actions and its environment to the PC. Meanwhile, the camera captures visual data and sends it to the PC. Then the PC can adjust camera settings as needed to optimize the user's experience. This flow ensures smooth communication between the user, glasses, PC, robot and camera, enabling a seamless augmented reality experience.



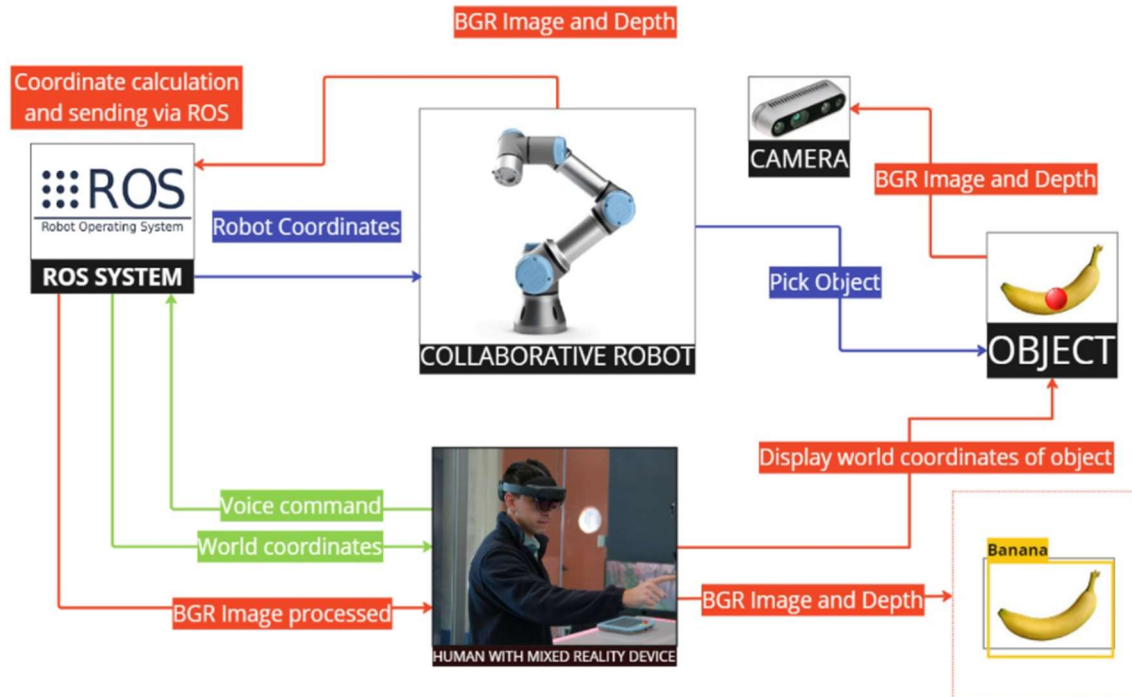


Figure 5. Main Flow of the Fruit Picking.

Main Capabilities

Considering the provided requirements, the main capabilities needed for the system:

- **User interaction:** Enable intuitive interaction through voice commands, gestures and gaze, facilitating seamless communication between human workers and the system.
- **Real-Time Visual Feedback:** Provide instant visual feedback via MR HoloLens glasses, displaying live camera views and object information to enhance situational awareness and facilitate decision-making.
- **Cognitive Assistance:** Support decision-making processes by processing visual data for object recognition, offering valuable insights and assisting in task prioritization within the system.
- **Robot Trajectory Optimization:** Enhance the collaborative robot's trajectory by coordinating its movements using real-time 3D object localization. This approach aims to improve task execution efficiency by refining the robot's movement path, ensuring precise trajectories towards identified objects within the workspace.
- **SSH / Human centricity context:** The applications raises questions of data protection and privacy if the cameras will be collecting and processes data that would make it possible to identify the human they are working with. the system must therefore consider the principles of privacy-by-design (e.g. blur the faces of the co-worker). We must also be mindful of long-term effects such as machine bias. We must be mindful of what the effects of these technologies are in the short term, but also what type of future they will create in the longer term. This raises questions of, for instance, job replacement. There might also be issues with human autonomy that we must explore.

For more information in the annexes the technical requirements, user interfaces, use cases and functional requirements.

3.3 Challenge 3- Flexible Collaborative robots (INT)

The integration of advanced solutions to support operators could reduce the production cycle time, increase the quality, and improve the operators' working conditions. However, in agile work environments, manufacturing companies need flexible solutions to cope with an increasing demand variety. To this purpose, flexibility should be guaranteed both at the hardware level (versatile grippers) and at the software level (behavior adaptiveness, hardware independency).

System Users	<ul style="list-style-type: none"> Collaborative robots, workers
Goals	<ul style="list-style-type: none"> Provide a reprogrammable robotics workstation adaptable to variable production requirements concerning hardware and software configuration.
Course taken	<ul style="list-style-type: none"> Ensure plug-and-play modularity of the hardware and software components to extend the robotics workstation's capabilities and increase adaptability.
Alternatives course	<ul style="list-style-type: none"> High variability of products: geometry, size, client personalization. Complex systems: the product is composed of numerous components. Support other processes: manage processes before and after the main task (e.g., quality control, packing, pre-assembly, etc.). Adapt the robot's behaviour to ensure workers' autonomy.
Commonalities in journeys	<ul style="list-style-type: none"> Shared working environments, workers' safety, adaptability to the production variations, and optimizing operators' involvement in repetitive tasks.

Table 3. Analysis for the Challenge 3.

3.3.1 Example: Assembly and packing robotic assistant

During production operations, robots can act as assistants for operators. For instance, the robot can provide the worker with all the components to finish the product and pass them in such a way as to safeguard the operator's ergonomics. Furthermore, the robot could perform fine manual operations where arm, wrist and finger injuries are critical. This case is often present in companies that produce non-standard products or use old industrial machines designed without considering physical ergonomics. Moreover, Flexible workstations represent viable reconfigurable solutions for managing the tasks at the end of the production line. In the above-proposed scenarios, HRI systems could represent a valuable solution that exploits robotics flexibility and relies on human oversight.



Below is one concrete application case related to the packing process at the end of a line in the automotive sector. Heavy products arranged in random positions and orientations must be placed in a preformed tray. This task requires high precision and significant force.



Figure 6. Example for Challenge 3.

In this application case, the robot should recognize and manage the heavy product, safeguarding the operator from injuries and safety problems, while the operator should monitor the robot's activity and intervene, for example, if inaccuracies occur or unexpected forces are requested to perform the task.

Actors: **Collaborative Robot and Operator**

(1) Collaborative Robot:

- Execute force operations
- Execute fine manual operation
- Share some task with human operators

(2) Human workers:

- Supervise the packing process
- Handle exceptions
- Manage the empty pre-formed tray layers or empty boxes
- Manage orders from company management system
- Coordinate shipment.

Main Flow

The operator selects the product to be packed from the database connected to the company's management system. The robot receives the product code information and obtains the necessary information to recognise it in the space (CAD and images) and the information on the related tray (dimensions, slots, etc.). The operator prepares the packing area by placing the first tray on a pallet. Following the command from the operator (physical interface or voice input), the robot recognises the object and its pose, picks it, and places it in one of the free slots. The positioning sequence in the slots is pre-programmed, as in palletising. The pre-formed tray constrains the product's positioning

and requires a specific force to achieve the correct coupling. If the robot cannot position the product in its final slot, the operator can intervene by physically acting on the robot to accompany the product into its slot. In this phase, the robot bears the product's weight and cooperates with the human to achieve precise positioning.

Once the tray is filled, the operator performs a quality check and sets up another tray until the desired number of trays for the current pallet is reached. At any time, the operator can stop, start or give high-level commands to the robot via physical interface or voice input. During the process, a camera monitors the operator's posture, and he is alerted if his ergonomic indexes fall below a threshold.

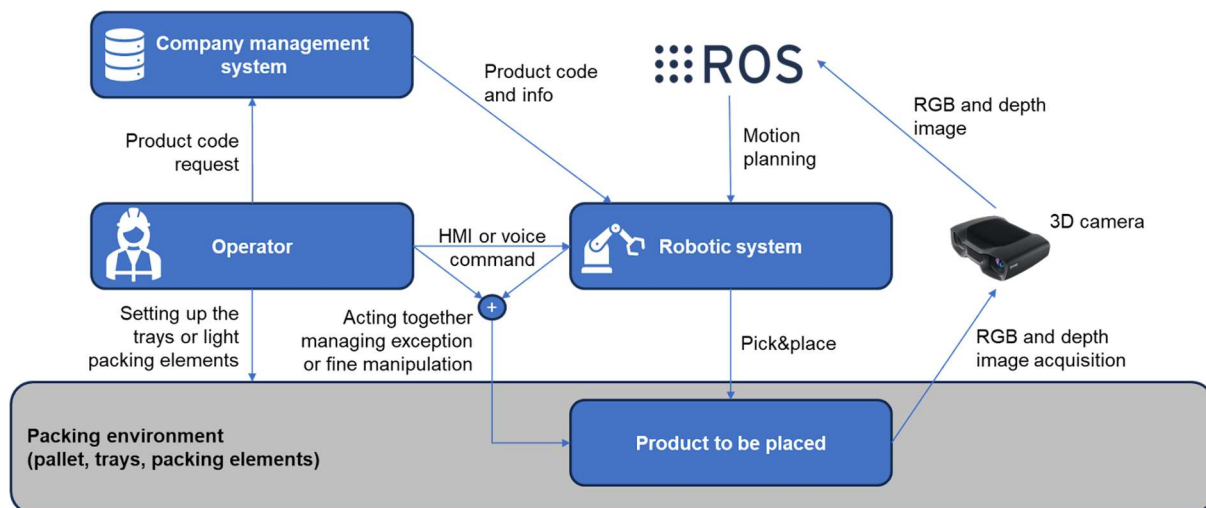


Figure 7. Main flow of the Assembly and packing robotic assistant.

Main capabilities:

- **Company system integration:** The system should connect to the company's management system and access the database containing product information, including product codes, CAD drawings, images, and tray specifications.
- **Object Recognition and Localization:** The robot should recognize objects based on their code information, obtaining the necessary information to identify their pose in space.
- **Tray Recognition and Constraints Handling:** The system should recognize the type of tray used, including specific dimensions, slots, and constraints. The robot must know these constraints to position the products within the tray properly.
- **Picking and Placing:** The robot should pick objects from a designated area and accurately place them in the desired slots within the tray. This task involves precise manipulation and control to ensure proper positioning and alignment.
- **Human-Robot Collaboration:** The system should support collaboration between the human operator and the robot. In particular, the operator should be able to physically intervene to assist the robot in positioning the product if necessary.
- **User Interaction:** The system should provide user-friendly interfaces, such as physical HMIs or voice command systems. These interfaces allow the operator to start, stop, or give high-level commands to the robot as needed.
- **Real-time Posture Monitoring:** The system should incorporate a camera-based posture monitoring system to track the operator's posture during packing. It should be capable of analysing posture data and alerting the operator if ergonomic indices fall below a certain threshold, indicating potential ergonomic risks.

- SSH / Human centricity context:** The applications raises questions of data protection and privacy if the cameras will be collecting and processes data that would make it possible to identify the human they are working with. the system must therefore consider the principles of privacy-by-design (e.g. blur the faces of the co-worker). We must also be mindful of long-term effects such as machine bias. We must be mindful of what the effects of these technologies are in the short term, but also what type of future they will create in the longer term. This raises questions of, for instance, job replacement. There might also be issues with human autonomy that we must explore.

For more information in the annexes the technical requirements, user interfaces, use cases and functional requirements for this example.

3.4 Challenge 4 – Smart Programming (INT)

To ensure adaptability to different products while preserving operators’ autonomy, the system should feature intuitive interfaces to make it easily reprogrammable by operators without coding skills.

System Users	<ul style="list-style-type: none"> Collaborative robots, workers
Goals	<ul style="list-style-type: none"> Enable workers without programming competencies to reprogram a robotics workstation easily and intuitively so as to face highly variable production.
Course taken	<ul style="list-style-type: none"> Integration of intuitive interfaces and AI algorithms to ensure flexibility and intuitiveness.
Alternatives course	<ul style="list-style-type: none"> Instead of considering specific hardware as intuitive interfaces, natural language and gesture recognition could be introduced. The robot's behaviour could be adapted to optimize workers' ergonomoy. Previous programming could be stored to facilitate potential reuse.
Commonalities in journeys	<ul style="list-style-type: none"> Shared working environments, workers safety, adaptability to production variations, optimizing operator’s involvement in repetitive tasks.

Table 4. Analysis for the Challenge 4.

3.4.1 Example: Robotic kitting assistant.

One of the standard and crucial phases in producing assembled parts is kitting. A specific product is selected from the company's management system, obtaining its Bill of Materials (BoM) with the various components and their location within the warehouse. Following a lean paradigm, all the items constituting the kit should be retrieved from a warehouse, bringing only what is needed to the assembly station. This application case considers both automated warehouses, involving a robotic cell, and non-automated warehouses, consisting of shelving, which humans should manage.



The challenge is to pick, from the automated warehouse, different items (sizes, colours, packaging) from different bins filled with multiple components of the same type and compose a bin with the components needed for assembly, namely the kit. Furthermore, given the large quantity of items, the robot should be able to pick the correct amount for each item without being pre-trained to recognize all objects. The operator collaborates with the robot during the kitting phase, picking items from non-automated warehouses, and together, they keep track of the items picked and those missing.

Once the kit is completed, the robot will bring it to the assembly station that requested it. In this application case, the robotic cell consists of an Autonomous Mobile Robot (AMR) and a robot arms or a service robot.



Figure 8. Example for the Challenge 4.

Actors: AMR, collaborative robots and workers

(1) Collaborative Robot + AMR:

- Offer a simple way to codify different objects
- Take input naturally from operators
- Autonomously create the kit
- Notify lack of necessary items
- Navigate autonomously inside the warehouse

(2) Human workers:

- Teach the robot on what it has to do
- Supervise the kitting process
- Handle exceptions
- Provide additional instructions if it is necessary
- Task and process scheduling

Main Flow:

- The operator selects a product to be assembled from the company management system, and the robot receives a list of objects, their quantity, and their location within the company. The items could be stored in an automated or non-automated warehouse.

- The operator reads the list from the robot's touch screen. The robot can move to the automated warehouse in follow-me mode with the operator or independently.
- The operator takes items from the shelves and places them inside the bin, which will constitute the assembly kit. Then, the operator updates the list of items to be picked via the screen or with natural language.
- While doing so, the robot will interface with the automated warehouse, requesting the bins with the remaining components. Once the selected bin is retrieved, the robot should pick the right number of items and move them to the assembly kit bin, updating the list of items.
- Once the list is complete, the operator performs a quality check and sends the robot to the assembly station that requested the kit.

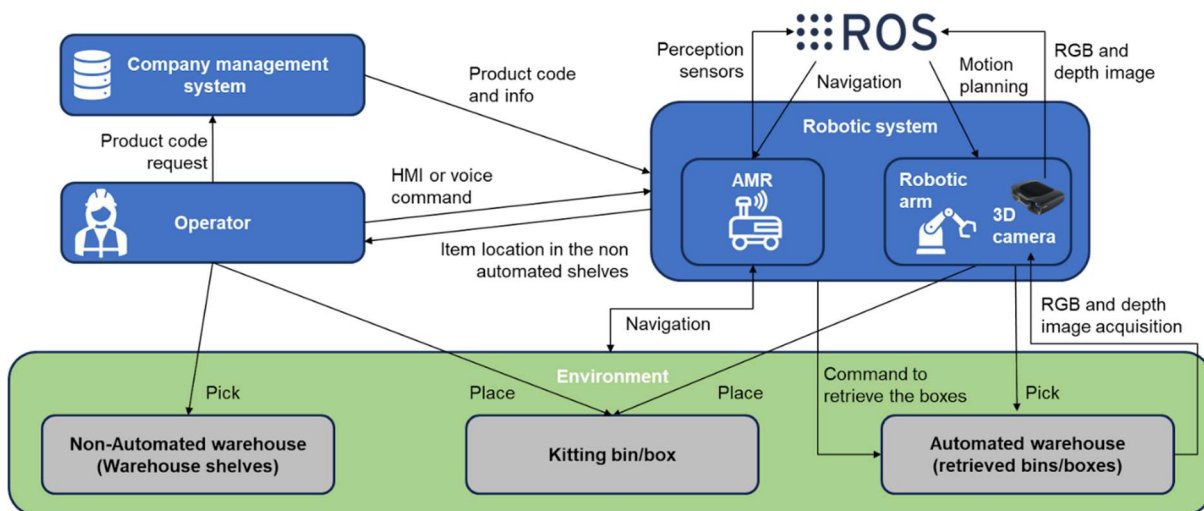


Figure 9. Main flow of the robotic kitting assistant

Main capabilities

- **Company system integration:** The system should interface with the company's management system to receive information about the selected product, including a list of objects, quantities, and locations within the company.
- **Automated Warehouse Interface:** The system should interface with automated warehouses, retrieving information about the location of items and requesting bins with specific components.
- **Operator Interface:** The system should provide an intuitive interface for the operator to illustrate the list of items and update it as items are picked. This interface could be a touch screen installed on the robot or a handheld device.
- **Navigation:** The system should support both follow-me modes, allowing the operator to accompany the robot to the warehouse if needed, and autonomous navigation, allowing the robot to reach the warehouse and the assembly station that requested the kit independently.
- **Item Retrieval and Placement:** The robot should retrieve the proper bins from the warehouse, identify and pick up the correct quantity of items, and place them into the assembly kit bin. The robotic system should rely on smart programming methodologies for the pick-and-place, such as reinforcement learning, learning from demonstration, etc.
- **List Update and Management:** The system should update the list of items as items are picked and placed (by the robot or human operator) into the assembly kit bin, ensuring accurate inventory tracking.

- Quality Check: Once the list is complete, the system should allow the operator to perform a quality check to ensure that all necessary items have been picked and placed correctly.
- SSH / Human centricity context: The applications raises questions of data protection and privacy if the cameras will be collecting and processes data that would make it possible to identify the human they are working with. the system must therefore consider the principles of privacy-by-design (e.g. blur the faces of the co-worker). We must also be mindful of long-term effects such as machine bias. We must be mindful of what the effects of these technologies are in the short term, but also what type of future they will create in the longer term. This raises questions of, for instance, job replacement. There might also be issues with human autonomy that we must explore.

For more information in the annexes the technical requirements, user interfaces, use cases and functional requirements for this example.

3.5 Challenge 5- Enhanced robot functionality through multimodal HRI interactions (PAL)

Challenge 5 focuses on enhancing the functionality of robots through advanced multimodal human-robot interactions. This challenge aims to improve how robots and humans collaborate on functional tasks by utilizing a combination of communication methods—verbal, gestures, and visual cues.

<p>System Users</p>	<p>Robot UX designers, robot programmers, non-expert users</p>
<p>Goals & main challenges</p>	<ul style="list-style-type: none"> • To enhance the interaction between non-roboticist/non-expert users (incl. vulnerable groups like hospital in-patients or older people) and robots by using multimodal communication (verbal, gestures, visual cues). Example of <i>enhancements</i> could include: <ul style="list-style-type: none"> ○ Better detection of user engagement/disengagement ○ More robust speech recognition ○ Building of persistent user profiles, storing users' preferences and desires ○ Integration of rich dialogue (eg, LLM-based) with user profiles ○ Better failure detection and recovery (eg when the robot does not successfully perform what the human is expecting) • To create an intuitive and user-friendly experience for non-expert users, enabling them to interact with robots for various assisted living tasks. • To ensure that the technology is adaptable, personalize, and human-centric, catering to the unique needs and preferences of each user.
<p>Course taken</p>	<ul style="list-style-type: none"> • The robot's role/functionality is defined using participatory methodology to fulfil a task/role that is relevant and important for the stakeholders

	<ul style="list-style-type: none"> • The robot adapts its behaviour and responses to the people it interacts with. For instance, in the healthcare environment, the robot's response to a similar request might differ depending on who is asking: staff, patients, family... • All users keep fully agency (including the ability not to interact/use the robot)
Specific challenges	<ul style="list-style-type: none"> • High variability of users/stakeholders • Changing, dynamic environment, including over the course of a single day (eg day/night; meal distribution time; family visits time; etc)
Commonalities in journeys	<ul style="list-style-type: none"> • Recognition of the importance of designing robots for and with the end-users/stakeholders • Recognition of the importance of safety and reliability in technology used in assisted living contexts.

Table 5. Analysis for the Challenge 5.

3.5.1 Example: Guided stretching session with an interactive robot



Figure 10. Example for the Challenge 5.

The application example looks into using an interactive social robot like PAL TIAGo (or PAL ARI, depicted above) to help with non-critical healthcare tasks, like physical exercising (e.g. stretching). The staff can program a set of stretching tasks that the robot performs with patients, while providing feedback and entertainment.

The robot is designed to learn and adapt to individual user preferences, limitations, and desires, providing a personalised and engaging care experience.

This use case demonstrates the robot's ability to adapt technology to the user's needs and environment, emphasising a human-centred approach in HRI. It showcases how robots can support personal growth and enrichment activities, making technology an empowering tool rather than a constraint.

Actors: Care staff, patients, interactive robot and care environment

- (1) Care staff, who have a mobile-based interface to program a schedule of physical activities.
- (2) Patients, with their own different needs, limitations, preferences.
- (3) The interactive robot, equipped with a range of sensing and interaction capabilities.

- (4) The care environment, including the physical building layout (e.g., location of the rooms, door, etc.) and organisational constraints (e.g., the schedule of the nurses/patients, the time of the meals, etc).

Main Flow:

While this example implies at least two interaction flows (with the care staff, to schedule and define the exercising routines; one with the patients themselves, to perform the exercise), we focus here on the robot-patient interaction flow, which is more interesting from an interaction perspective.

A possible patient-robot interaction flow would include:

- 1. User interest and skill level assessment:
 - Through a friendly conversation, the robot assesses the user's current skill level and specific interests using speech recognition.
 - The robot personalizes the exercising session based on the user's responses and observable cues.
- 2. Step-by-step instruction:
 - The robot provides step-by-step instructions for the session, utilizing multimodal communication (demonstration with its own arms, visual aids on a screen, verbal instructions,).
 - It monitors the user's progress using activity recognition and adjusts the pace or repeats instructions as needed.
- 3. Interactive feedback and encouragement:
 - The robot recognizes signs of frustration or confusion in the user through facial expression and activity recognition.
 - It offers encouragement, suggests breaks, or modifies the teaching method to keep the session enjoyable and effective.
- 4. Skill practice and fine-tuning:
 - The user practises the new skill with the robot providing real-time feedback and tips for improvement.
 - The robot encourages exploration and creativity, adapting the session to incorporate the user's ideas and preferences.
- 5. Review and future suggestions:
 - At the end of the session, the robot reviews the user's achievements and areas for improvement.
 - Based on the user's engagement and feedback, the robot suggests future sessions or related hobbies that might be of interest.
 - The robot stores the resulting personalised profile, so that it can be retrieved the next time the same user interacts with the robot.

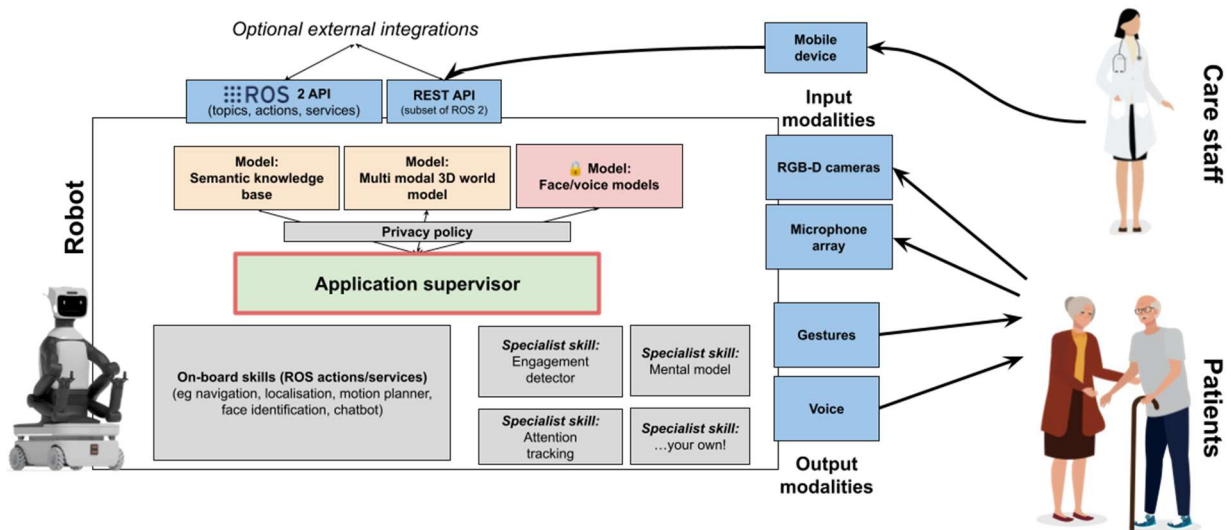


Figure 11. Main flow for Guided stretching session.

In terms of system architecture (cf figure), this example includes:

- Custom application supervisor, where the overall logic of the application is implemented
- Several custom *skills*, possibly building on top of off-the-shelf ones, to provide interaction capabilities (see below the main required capabilities)
- Integration of a mobile phone application for the staff to control the robot and setup the exercises

Example scenario: Guided Stretching Session with TIAGo

Scene 1: Identifying Needs and Setting Goals

- Helena, who has been feeling stiff from sitting too long at his desk job, decides it's time to incorporate more stretching into his daily routine. He tells TIAGo, "I need to start stretching, but I'm not sure where to begin."
- TIAGo, utilizing its speech recognition capability, responds encouragingly, "Stretching is a great way to improve flexibility and reduce stress. Let's assess your current flexibility level and what you're comfortable with to tailor a stretching routine for you."

Scene 2: Preparing the Space and the User

- TIAGo guides Helena in preparing a safe and comfortable space for stretching. "Let's clear a bit of space on the floor and grab a yoga mat if you have one."
- Using object recognition, TIAGo checks the surroundings to ensure there's enough space and the floor is clear of any objects that might interfere or cause injury.

Scene 3: Demonstrating and Guiding Through Stretches

- TIAGo starts the session with a simple stretching routine, displaying instructional videos on a screen for visual aid and providing verbal instructions. "We'll begin with some neck and shoulder stretches to relieve tension."
- As Helena follows along, TIAGo monitors his movements through activity recognition, ensuring he is performing the stretches correctly and safely.

Scene 4: Providing Feedback and Encouragement

- Noticing Helena struggling with a particular stretch, TIAGo uses its understanding of human posture to provide specific advice. "Try to keep your back straight as you reach down. It's okay if you can't touch your toes; just go as far as you can comfortably."
- TIAGo offers encouragement and modifies the routine to include more beginner-friendly stretches, ensuring Helena remains motivated and does not push beyond his limits.

Scene 5: Adaptation and Personalization

- Observing Helena's progress and preferences, TIAGo adapts the session, introducing new stretches that target areas of stiffness and adjusting the difficulty level based on his feedback and performance.
- TIAGo encourages Helena to explore different stretches, teaching him how to listen to his body and adjust his movements for maximum benefit.

Scene 6: Review and Recommendations for Future Sessions

- At the end of the session, TIAGo reviews the stretches with Helena, highlighting his improvements and areas to focus on in future sessions.
- "You did a great job today, Helena! I've noticed an improvement in your flexibility already. Would you like me to schedule regular stretching sessions to help you keep on track?"

Main Capabilities

- **Speech recognition and Natural language processing:** understanding and responding to voice commands, facilitating ease of use without requiring manual programming or control. While PAL robots provide out-of-the-box speech recognition (based on vosk) and dialogue management (using the RASA chatbot), alternatives can be explored (in particular, the use of LLMs to provide rich and flexible dialogue capabilities);
- **User profile representation and storage.** The robot's knowledge base could be used for this purpose; the retrieval of the user profile and its use to scaffold dialogue would need to be developed;
- **Activity recognition:** understand human activity, enabling it to react or adjust its behaviour based on what it detects. In the context of this example, the robot needs to recognise whether the user is performing the exercise appropriately; Recognition of activity disengagement (eg if the user wants to stop, or leaves) is also important;
- **People recognition:** using the ROS4HRI framework, the robot needs to offer solid and multi-modal (face, body, voice) people identification (so that when a previous user come back, the robot recognises it);
- **Facial expression and emotion recognition:** the robot uses visual processing to identify human facial expressions and infer emotions;
- **Adaptive learning algorithms:** These algorithms enable the robot to learn from experiences and interactions, adapting its responses and behaviours over time to improve performance and user satisfaction;
- **Multimodal communication:** Involves the robot using multiple forms of communication such as speech, text, gestures, and visual displays—to interact more effectively with humans.
- **SSH / Human centricity context:** The applications raises questions of data protection and privacy if the cameras will be collecting and processes data that would make it possible to identify the human they are working with. the system must therefore consider the principles of privacy-by-design (e.g. blur the faces of the co-worker). We must also be mindful of long-term effects such as machine bias. We must be mindful of what the effects of these technologies are in the short term, but also what type of future they will create in the longer

term. This raises questions of, for instance, job replacement. There might also be issues with human autonomy that we must explore.

For more information in the annexes the technical requirements, user interfaces, use cases and functional requirements for this example.

3.6 Challenge 6 – Fetch & carry tasks in healthcare environments (PAL)

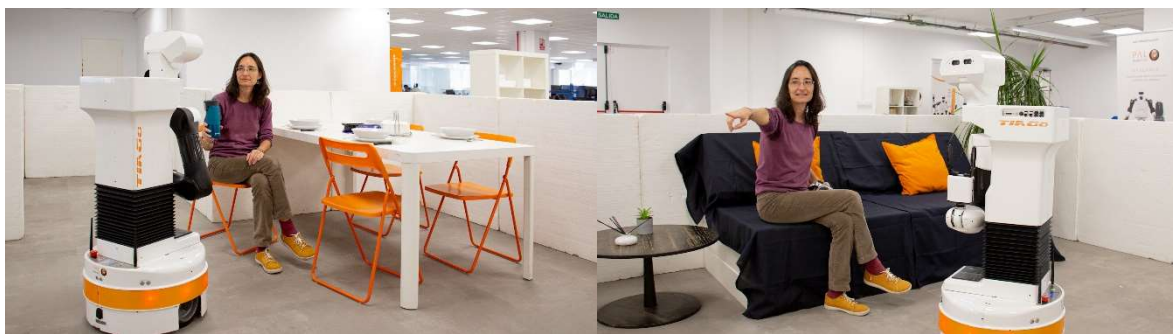


Figure 12. Example for the Challenge 6.

Challenge 6 addresses the development and implementation of robotic systems designed to autonomously perform fetch and carry tasks within healthcare settings. By automating these routine tasks, the aim is to free up medical staff to focus on direct patient care and other critical responsibilities, enhancing overall efficiency and care quality in hospitals.

<p>System Users</p>	<ul style="list-style-type: none"> • Hospital staff, hospital technical staff (eg IT services), patients, other hospital visitors
<p>Goals</p>	<ul style="list-style-type: none"> • To improve the reliability of mobile manipulators like PAL TIAGo when executing autonomous fetch&carry tasks in social environments <ul style="list-style-type: none"> ○ Ability to deal with complex, dynamic indoor environments (like hospital) ○ Ability to handle doors, elevators ○ Detailed introspection and context-awareness to provide appropriate feedback during the task execution, including requesting help from surrounding humans • To develop a robust and mature interaction flow to command the robot to fetch or bring arbitrary items from a place to another • To build a system that end-users trust and are willing to use on a day-to-day basis • To build a social navigation system that is safe and legible when crossing path with people • Look at the specific case of the healthcare/hospital environment
<p>Course taken</p>	<ul style="list-style-type: none"> • Enable the robot to autonomously perform fetch and carry tasks to support the hospital staff.

	<ul style="list-style-type: none"> • Enable the robot to perform other similar low-added-value tasks
Alternatives course	<ul style="list-style-type: none"> • Variability of objects to be picked • Changing, dynamic building environment, including over the course of a single day (eg day/night; meal distribution time; family visits time; etc)
Commonalities in journeys	<ul style="list-style-type: none"> • Interactions with the various people in the hospital eco-system (nurses, doctors, patients, visitors) • Handling of navigation in complex, dynamic environments like hospitals

Table 6. Analysis for the Challenge 6.

3.6.1 Example: Asking for help while carrying medical samples

This case focuses on using assistive robots for the safe and efficient transportation of medical samples between patient wards and laboratories within healthcare environments.

In case of the robot being blocked (for instance, because of a hospital bed blocking the passage in a corridor), the robot looks for someone, and asks for help.

Actors: Hospital staff and mobile manipulator (like PAL TIAGo robot)

Main Flow

Two interaction flows need to be considered:

- **Fetch&carry flow**, where a staff member calls the robot, and requests it to bring a medical sample to a known location (eg, the hospital laboratory). The nurse places the sample on the robot, and let the robot go;
- **Help requests flow**, where the robot's navigation is interrupted (due object blocking the passage, closed door, elevator...), and the robot looks for help.

The figure below illustrates the *fetch&carry flow*: the caregiver calls the robot, either via a mobile app (if the robot is far), or by direct communication (verbal or gesture); the robot approaches the user (close-proximity social navigation; step 1 on the figure); the user provides the medical sample and indicates verbally the destination; the robot acknowledge the task and destination, and starts the navigation (socially-aware navigation, step 2).

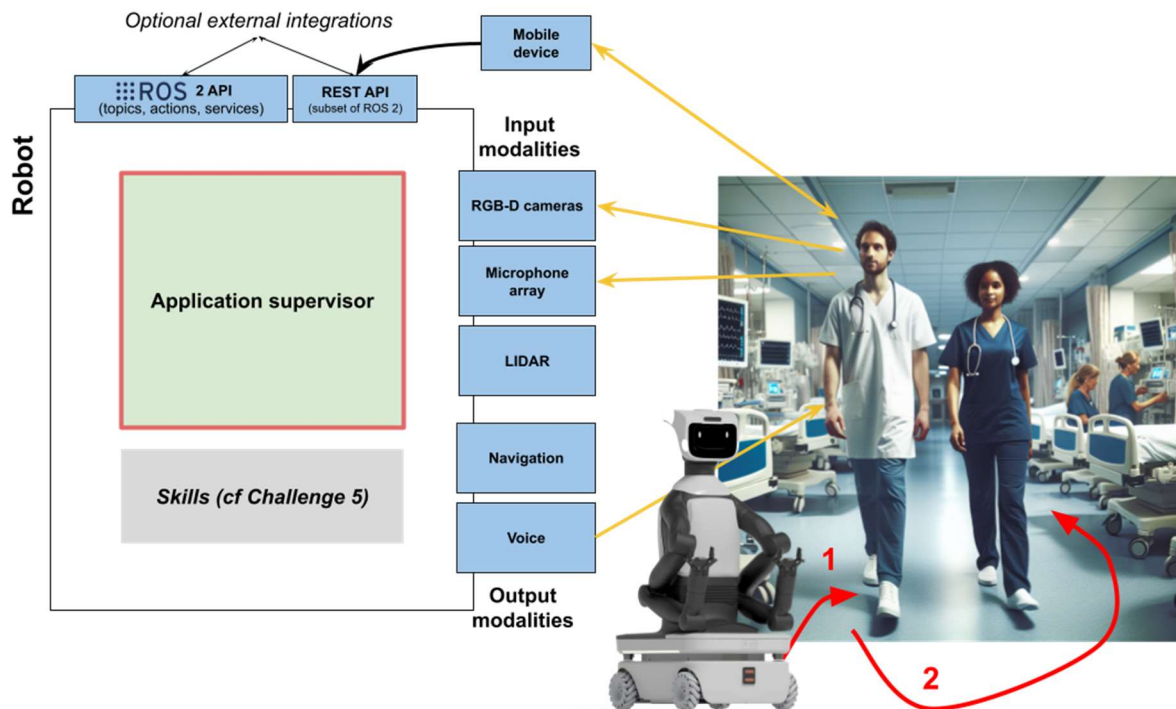


Figure 13. Main flow for asking for help and medical samples.

Extensions

- **Priority Handling:** the robot manages urgent sample deliveries with priority, adjusting schedules as needed.
- **Rerouting for Delays:** If faced with delays, the robot finds alternative routes, updating delivery times in the system.
- **Special Handling Communication:** Lab technicians can provide special handling instructions to the robot directly, ensuring proper care of sensitive samples.

Main Capabilities

- **Social navigation:** navigate around humans in complex, dynamic environments, accounting for social norms (eg, do not navigate too close to humans; do not plan a path going through a group of people; etc);
- **Navigation for social approaches:** when the robot needs to get close to a human (to eg fetch an item), it needs to plan for an appropriate approach trajectory;
- **Activity and group recognition:** understand human(s) activity, enabling it to react or adjust its behaviour based on what it detects;
- **Speech recognition and Natural language processing:** understanding and responding to voice commands, facilitating ease of use without requiring manual programming or control. While PAL robots provide out-of-the-box speech recognition (based on vosk) and dialogue management (using the RASA chatbot), alternatives can be explored (in particular, the use of LLMs to provide rich and flexible dialogue capabilities);
- **People recognition:** using the ROS4HRI framework, the robot needs to offer solid and multi-modal (face, body, voice) people detection;
- **Multimodal communication:** Involves the robot using multiple forms of communication—such as speech, text, gestures, and visual displays—to interact more effectively with humans.

- SSH / Human centricity context:** the application might be sensitive due to its setting (a hospital), which might require collecting and processing data relating to patients. This might be qualified als health data. This means that we must be mindful of general data protection and privacy issues, but also consider the issues relating to the collection and processing of sensitive (health) data. Other issues relate to whether or not the robot will be interacting with patients. This raises two potential issues: accountability and liability, and human dignity. We must ensure that, if the robot interacts with patients, their privacy is being protected, they are not treated as objects in order for their human dignity to be guaranteed, and it must be clear who is accountable in case accidents happen. There must also be enough attention to avoid any kind of bias when the robot is responding to human communication.

For more information in the annexes the technical requirements, user interfaces, use cases and functional requirements for this example.

3.7 Challenge 7 – HRI for improving the efficiency of workers in high precision flexible tasks (POL)

In manufacturing environments, high precision tasks which require a high level of process variety have been done by operators. In such tasks, the setup time is extremely high, for example, due to the selection of proper tools. In addition, satisfying the ambition of zero-defect manufacturing entails reworking of workpieces that did not pass the quality control, which is considered a high-precision task. This challenge addresses the deployment of Human-Robot Interaction (HRI) to improve the efficiency of operators working on tasks which require a high level of precision and flexibility by preparing the workspace for operators, aiming at reducing the overall setup time.

System Users	<ul style="list-style-type: none"> Operator, robotic arms, AGV (Automated Guided Vehicle)
Goals	<ul style="list-style-type: none"> To improve the efficiency of operators in high-precision flexible tasks by preparing working set-ups in advance. More specifically, selecting and picking & placing the proper tools and functional components for the reworking process.
Course taken	<ul style="list-style-type: none"> Defect detection of components at the control station, Automatic loading of defective products on the AGV pallet through a robotic arm, Automatic preparation of workspace for reworking on defective products
Alternatives course	<ul style="list-style-type: none"> Automatic reconfiguration of the defective parts' production routes in the production line
Commonalities in journeys	<ul style="list-style-type: none"> Shared working environment between the operator and the robot, Operator's well-being: by preparation of his/her workspace in advance <p>Handling of objects with the variation in shapes and sizes</p>

Table 7. Analysis of the Challenge 7.

3.7.1 Example: PCB Desoldering

Reworking of printed circuit boards (PCBs) which did not pass the quality control check is considered a high-precision task. Defective PCBs should be recovered, i.e., defective components must be identified and replaced by operational ones. The process of replacing components is intricate and time-consuming, in the sense that an operator must (i) recognize the defective components on the board by the information received from the quality control station, (ii) pick the functional component among the pool of components (it may be time-consuming, due to similarity of components, for example, resistors with identical shape and different resistance values), (iii) select the suitable tools among the available tools, depending on the type of components and the level of operator expertise, (iv) solder and desolder components taking into account to avoid applying excessive heat to components and board, to orient components correctly, to inspect new soldered joints, and etc., which causes high levels of physical and mental stress on them.

Actors: Human workers, UR5e Robot, AGV

The proposed solution is aimed at dedicating tasks (ii) and (iii) to a cobot such that the operator's workload is facilitated, and the operator focuses more on the meticulous task of soldering/desoldering. The cobot should be able to set up the working space of the operator before the arrival of the defective PCBs to be reworked, predicting the toolset for the operator by the information extracted from the quality control check and displacing it according to the different operators in charge of the operation considering their comfort and ergonomics.

Main Flow:

Defective PCBs are carried by an Automated Guided Vehicle (AGV) from the control station room to the reworking station room. In the meantime, the UR5e is preparing the rework station by the data received from the control unit. Particularly, the robot first identifies the proper tools and functional components from the available pool of tools and components via computer vision, then picks and places them on the table. In more detail, the RealSense camera D435i captures both the BGR and depth images of the pool of tools and sends them to the PC. On the PC, through object detection algorithms, the desired tools and components are selected, and their positions are calculated with respect to the robot coordinate. Afterward, the joint trajectories of the robot are calculated and sent to the robot for the execution of trajectories. In addition, to enable AGV to move autonomously and to navigate across the shop floor, it is required to provide a map of the building and to implement object avoidance algorithms on it.

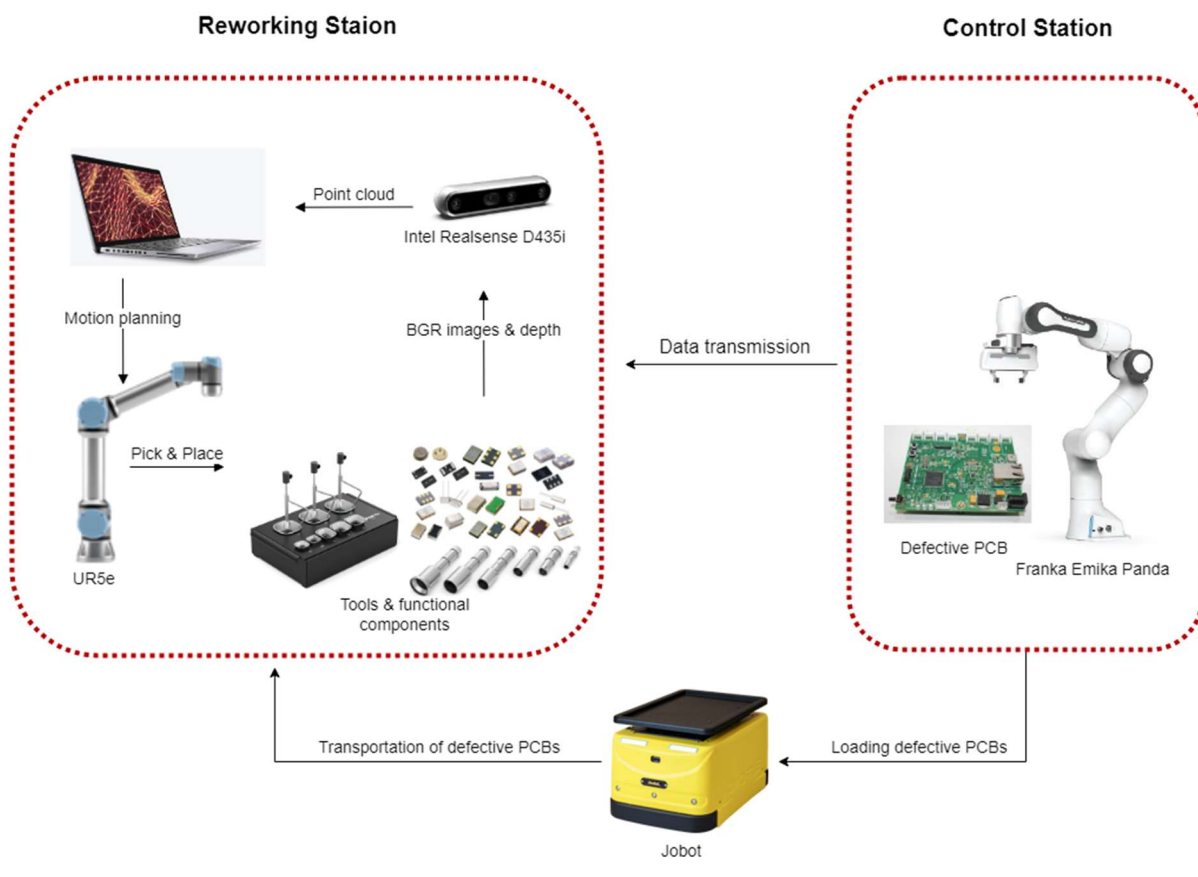


Figure 14. Main Flow for PCB Desoldering.

Capabilities:

- **Real-Time 3D Object Detection:** The objects should be localised in real-time, and their 3D poses must be determined precisely with respect to the base coordinate of the robotic arm.
- **Robotic Arm Trajectory Planning:** The estimated pose of detected objects will be sent to the robot's controller in real-time for trajectory planning.
- **Position-based Visual Servoing:** The tasks of pick and place of objects are executed via real-time 3D pose estimation of objects extracted from the camera, considering the robot's kinematic constraints.
- **Mobile Robot Navigation:** Optimised navigation and localization of mobile robots for the faster transportation of PCBs.
- **SSH / Human centricity context:** The applications raises questions of data protection and privacy if the cameras will be collecting and processes data that would make it possible to identify the human they are working with. the system must therefore consider the principles of privacy-by-design (e.g. blur the faces of the co-worker). We must also be mindful of long-term effects such as machine bias. We must be mindful of what the effects of these technologies are in the short term, but also what type of future they will create in the longer term. This raises questions of, for instance, job replacement. There might also be issues with human autonomy that we must explore.

For more information in the annexes the technical requirements, user interfaces, use cases and functional requirements for this example.

3.8 Challenge 8 – HRI for improving ergonomics in high precision tasks (POL)

This challenge aims at improving human ergonomics and comfort while doing a high-precision task with the deployment of HRI. Precision manual tasks that entail working with small-dimensional and delicate objects, usually require some dedicated fixed frame, whose setup-time takes time from the main activities of the operator. An inappropriate adjustment of a fixed frame, over time causes health issues, for example, chronic stiff neck. The cobot should automatically position and hold the workpiece according to the operator’s ergonomics and comfort.

System Users	<ul style="list-style-type: none"> Operator, robotic arms
Goals	<ul style="list-style-type: none"> To improve the ergonomics of operators in high-precision tasks based on his/her physical characteristics.
Course taken	<ul style="list-style-type: none"> Automatic positioning and holding of a workpiece according to operators' ergonomics, Positioning and orienting the robotic arm via voice command
Alternatives course	<ul style="list-style-type: none"> Positioning and orienting the robotic arm via hand gesture detection
Commonalities in journeys	<ul style="list-style-type: none"> Shared working environment between the operator and the robot, Operator’s well-being in terms of ergonomics: by holding a workpiece in the suitable position and orientation Handling of objects with the variation in sizes

Table 8. Analysis of the Challenge 8.

3.8.1 Example: Workpiece Holder.

The robot holds the workpiece in the appropriate position and orientation while an operator is working on it. Through the machine vision, the physical features of the operator including the height, and neck length are provided to the robot for calculating the right position and orientation of the workpiece considering the ergonomics and comfort of the operator. In addition, for the further adjustment of orientation, the operator sends a speech command to the robot.

Actors: Operator, UR5e robot



In the conventional solution, to adjust the orientation and position of a workpiece with respect to an operator, a desk with adjustable height and angle has been used. This solution has limitations in terms of number of degrees of freedom and a restricted range of adjustability. In the proposed solution, a robot with 6 degrees of freedom adjusts the workpiece orientation in a wide range of poses compared to the desk solution. In addition, the suitable pose of the workpiece is estimated according to the physical parameters of operators through images acquired via a 3D camera. For further adjustment and more intuitive interaction to the robot, the operator can send movement commands to the robot verbally.

Main Flow:

The RealSense camera D435i captures both the BGR and depth images of the operator and sends them to the PC. On the PC, through human detection algorithms, the relevant physical features of the operator are extracted. Consequently, the appropriate ergonomics and comfort of the operator are defined. In the next step, the desired joint angles of the robot are obtained and sent to the robot for holding the workpiece. In addition, the operator's speech is captured and then pre-processed to remove noise and enhance the speech signal, and then using the machine learning algorithm to recognize the words and convert them into text. The provided text is further analysed to perceive the orally communicated command. Accordingly, the robot makes the required adjustment.

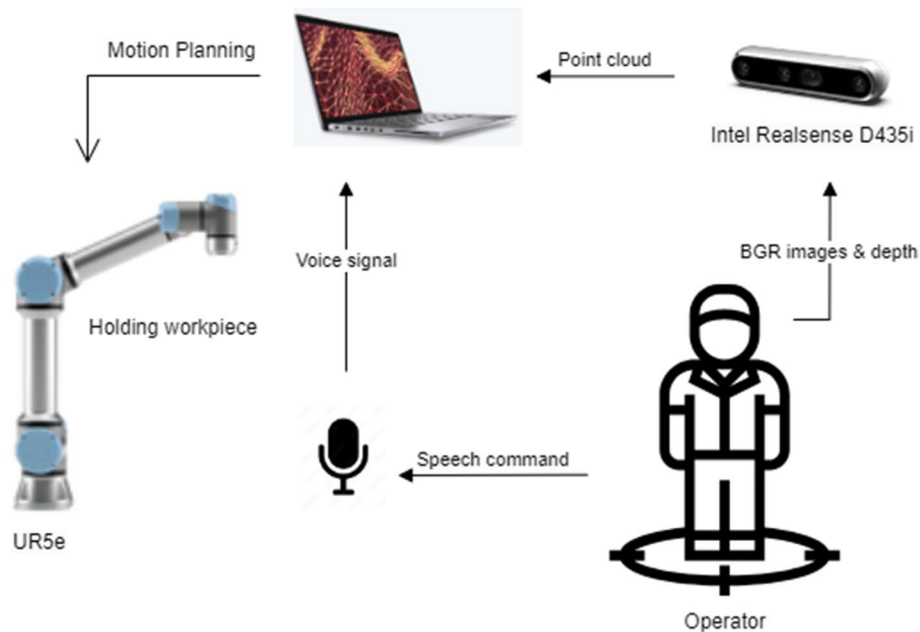


Figure 15. Main Flow for Workpiece Holder.

Extensions:

- Stress recognition:** In the method (i), the operator's stress is recognized by detection and interpretation signs of stress from facial expressions. In the method (ii), the stress is recognized from characteristics of a person's speech like pitch, intonation, speech rate, volume, and etc. The main challenges are high variations in the speech patterns and facial expressions across individuals with cultural differences as well as lighting conditions, head poses, and background noises.

Capabilities:



- **Speech Command detection:** The operator’s voice should be robustly recognized in the presence of environmental noises in real-time.
- **Ergonomics & comfort recognition:** The relevant operators’ physical parameters are detected through the machine vision to determine the robot configuration, considering the operator’s ergonomics.
- **SSH / Human centricity context:** the application must consider issues of bias when it aims to interpret stress based on facial expressions. It must be investigated whether it is feasible to detect stress in this manner. We will furthermore investigate the other issues that apply to the other use cases: privacy and data protection, machine bias and the impact of this application on the long-term future and human autonomy.

For more information in the annexes the technical requirements, user interfaces, use cases and functional requirements for this example.

1. ANNEX(ES)

Example: Battery Disassembly (CAR)				
Technical Requirements	<ol style="list-style-type: none"> 1. A proper power supply for the devices that are needed to run the algorithms, devices such as PCs and robots. 2. Battery of MR glasses must be charged properly. 3. If a fault occurs or is about to occur, the control strategy will adjust the settings to reverse it or prevent it. 4. Communication between network devices connected. Example: camera connected to the pc through USB-C wire. 			
User Interfaces	Digital interface integrated in the mixed reality application. The user interacts with this interface by means of gestures, voice and gaze.			
Use cases	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="background-color: #d8bfd8;">Actor: 3-Dimensional camera</td> </tr> <tr> <td style="background-color: #d8bfd8;"> <ol style="list-style-type: none"> 1. Extract BGR and depth images of the project. 2. Send the images to the PC. </td> </tr> <tr> <td style="background-color: #d8bfd8;">Actor: PC</td> </tr> </table>	Actor: 3-Dimensional camera	<ol style="list-style-type: none"> 1. Extract BGR and depth images of the project. 2. Send the images to the PC. 	Actor: PC
Actor: 3-Dimensional camera				
<ol style="list-style-type: none"> 1. Extract BGR and depth images of the project. 2. Send the images to the PC. 				
Actor: PC				

	<ol style="list-style-type: none"> 1. Transform coordinates between the reference frames of the robot, the camera and HoloLens 2 2. Transforming screw coordinates into instructions for the robot 3. Send processed BGR images and world coordinates to MR glasses via ROS 4. Process the BGR image to detect and locate the screws. 5. Monitoring the interaction between the robot and the human worker. 6. Transform text strings to audio and play them on speaker phone 7. Manage events and convert messages into electrical signals to change the colour of the table lights.
	<p>Actor: Collaborative Robot</p>
	<ol style="list-style-type: none"> 1. Picking up and placing screws inside your workspace
	<p>Actor: MR HoloLens glasses</p>
	<ol style="list-style-type: none"> 1. Display World coordinates of screws 2. Display BGR image processed 3. Track the user's hands, voice and eyes 4. Guide the user during the execution of the activity by means of holograms
	<p>Actor: Human workers</p>
	<ol style="list-style-type: none"> 1. Supervise the process 2. Establish the framework 3. Choosing which screws to pick 4. Collect uncollected bolts and report this event to the system
<p>Functional Requirements</p>	<ol style="list-style-type: none"> 1.The robot must have a safety button to stop the robot in case of failure. 2.The system must be scalable and able to handle more possible future programs. 3. The system must be fast enough to give a quick and synchronized response to the user. 4.The camera must capture real-time images with a minimum resolution of 1280x720 pixels. 5.The camera should capture depth data to an accuracy of 10 mm. 6.The system must filter out the 3D coordinates of objects that are not relevant to the robot's task. 7. The system must send the 3D coordinates of the objects to the robot in real time. 8. The augmented reality glasses should superimpose the 3D coordinates of the identified objects on the first-person view.

	<p>9.The system must recognize the user's voice commands with 95% accuracy.</p> <p>10.The system must provide feedback to the user on the voice commands it has recognized.</p> <p>11. The user can perform other tasks while the robot is working.</p>
<p>Non-functional requirements</p>	<p>Human-centric aspects (Ethical issues, Safety)</p>
	<ul style="list-style-type: none"> • The system must make sure that the human is not identifiable; it must blur the faces of the human • There must be a safety protocol and training • There must be a protocol about who is responsible if there are any accidents in practice • The human must have autonomy in how to execute its job

<p>Example: Fruit picking (CAR)</p>	
<p>Technical Requirements</p>	<p>1. A proper power supply for the devices that are needed to run the algorithms, devices such as PCs and robots.</p> <p>2.Battery of AR glasses must be charged properly.</p> <p>3.If a fault occurs or is about to occur, the control strategy will adjust the settings to reverse it or prevent it.</p> <p>4.Communication between network devices connected. Example: camera connected to the pc through USB-C wire.</p>
<p>User Interfaces</p>	<p>Digital interface integrated in the mixed reality application. The user interacts with this interface by means of gestures, voice and gaze.</p>
<p>Use cases</p>	<p>Actor: 3-Dimensional camera</p> <ol style="list-style-type: none"> 1. Extract BGR and depth images of the project. 2. Send the images to the PC. <p>Actor: PC</p>

	<ol style="list-style-type: none"> 1. Transform coordinates between the reference frames of the robot, the camera and HoloLens 2. 2. Transform the coordinates to robot reference space and world 3. Transforming screw coordinates into instructions for the robot 4. Calculate the anchorage points of the fruits to know which is the rotation that the robot has to make to pick them up. 5. Send processed BGR images and world coordinates to MRAR glasses via ROS 6. Process the BGR image to detect and locate the screws. 7. Monitoring the interaction between the robot and the human worker. 8. Transform text strings to audio and play them on speaker phone 9. Manage events and convert messages into electrical signals to change the colour of the table lights.
	<p>Actor: Collaborative Robot</p> <ol style="list-style-type: none"> 1. Pick a fruit
	<p>Actor: AR HoloLens glasses</p> <ol style="list-style-type: none"> 1. Display World coordinates of objects 2. Display BGR image processed 3. Track the user's hands, voice and eyes 4. Guide the user during the execution of the activity by means of holograms
	<p>Actor: Human workers</p> <ol style="list-style-type: none"> 1. Supervise the process 2. Establish the framework 3. Choosing which fruits to pick
	<p>Functional Requirements</p> <ol style="list-style-type: none"> 1.The robot must have a safety button to stop the robot in case of failure. 2.The system must be scalable and able to handle more possible future programs. 3. The system must be fast enough to give a quick and synchronized response to the user. 4.The camera must capture real-time images with a minimum resolution of 1280x720 pixels. 5.The camera should capture depth data to an accuracy of 10 mm. 6.The system must filter out the 3D coordinates of objects that are not relevant to the robot's task. 7. The system must send the 3D coordinates of the objects to the robot in real time.

	<p>8. The augmented reality glasses should superimpose the 3D coordinates of the identified objects on the first-person view.</p> <p>9. The system must recognize the user's voice commands with 95% accuracy.</p> <p>10. The system must provide feedback to the user on the voice commands it has recognized.</p>
Non-functional requirements	Human-centric aspects (Ethical issues, Safety)
	<ul style="list-style-type: none"> • The system must make sure that the human is not identifiable; it must blur the faces of the human • There must be a safety protocol and training • There must be a protocol about who is responsible if there are any accidents in practice • The human must have autonomy in how to execute its job

Example: Assembly and packing robotic assistant (INT)	
Technical Requirements	1. 3D point cloud-cad matching, Collaborative robots, force control, 3d camera to recognize objects to pick, 3d camera for the operator physical ergonomic monitoring, microphone, HMI/GUI, communication with company management system
User Interfaces	GUI, intuitive interfaces, voice
Use cases	Actor: Robot
	<ol style="list-style-type: none"> 1. Execute force operations 2. Execute fine manual operation 3. Recognize and manipulate different objects 4. Share some task with human operators
	Actor: System
	<ol style="list-style-type: none"> 1. Provide additional instructions if it is necessary 2. Task and process scheduling
	Actor: Human workers

	<ol style="list-style-type: none"> 1. Supervise the production process 2. Perform quality control tasks
<p>Functional Requirements</p>	<ol style="list-style-type: none"> 1. Company system integration: The system should connect to the company's management system and access the database containing product information, including product codes, CAD drawings, images, and tray specifications. 2. Object Recognition and Localization: The robot should recognize objects based on their code information, obtaining the necessary information to identify their pose in space. 3. Tray Recognition and Constraints Handling: The system should recognize the type of tray used, including specific dimensions, slots, and constraints. The robot must know these constraints to position the products within the tray properly. 4. Picking and Placing: The robot should pick objects from a designated area and accurately place them in the desired slots within the tray. This task involves precise manipulation and control to ensure proper positioning and alignment. 5. Human-Robot Collaboration: The system should support collaboration between the human operator and the robot. In particular, the operator should be able to physically intervene to assist the robot in positioning the product if necessary. 6. User Interaction: The system should provide user-friendly interfaces, such as physical HMIs or voice command systems. These interfaces allow the operator to start, stop, or give high-level commands to the robot as needed. 7. Real-time Posture Monitoring: The system should incorporate a camera-based posture monitoring system to track the operator's posture during packing. It should be capable of analysing posture data and alerting the operator if ergonomic indices fall below a certain threshold, indicating potential ergonomic risks.
<p>Non-functional requirements</p>	<p>Human-centric aspects (Ethical issues, Safety)</p>
	<ul style="list-style-type: none"> • The system must make sure that the human is not identifiable; it must blur the faces of the human • There must be a safety protocol and training • There must be a protocol about who is responsible if there are any accidents in practice • The human must have autonomy in how to execute its job

Example: Robotic kitting assistant (INT)	
Technical Requirements	<ol style="list-style-type: none"> 1. Flexible picking algorithm, AMR, Collaborative robots, 3d camera to recognize objects to pic, microphone, HMI/GUI, communication with company management system
User Interfaces	GUI, intuitive interfaces, voice
Use cases	Actor: Robot
	<ol style="list-style-type: none"> 1. Offer a simple way to codify different objects 2. Take input naturally from operators 3. Autonomously create the kit 4. Notify lack of necessary items
	Actor: System
	<ol style="list-style-type: none"> 1. Provide additional instructions if it is necessary 2. Task and process scheduling
	Actor: Human workers
	<ol style="list-style-type: none"> 1. Teach the robot on what it has to do 2. Supervise the kitting process 3. Handle exceptions

<p>Functional Requirements</p>	<ol style="list-style-type: none"> 1. Company system integration: The system should interface with the company's management system to receive information about the selected product, including a list of objects, quantities, and locations within the company. 2. Automated Warehouse Interface: The system should interface with automated warehouses, retrieving information about the location of items and requesting bins with specific components. 3. Operator Interface: The system should provide an intuitive interface for the operator to illustrate the list of items and update it as items are picked. This interface could be a touch screen installed on the robot or a handheld device. 4. Navigation: The system should support both follow-me modes, allowing the operator to accompany the robot to the warehouse if needed, and autonomous navigation, allowing the robot to reach the warehouse and the assembly station that requested the kit independently. 5. Item Retrieval and Placement: The robot should retrieve the proper bins from the warehouse, identify and pick up the correct quantity of items, and place them into the assembly kit bin. The robotic system should rely on smart programming methodologies for the pick-and-place, such as reinforcement learning, learning from demonstration, etc. 6. List Update and Management: The system should update the list of items as items are picked and placed (by the robot or human operator) into the assembly kit bin, ensuring accurate inventory tracking. 7. Quality Check: Once the list is complete, the system should allow the operator to perform a quality check to ensure that all necessary items have been picked and placed correctly.
<p>Non-functional requirements</p>	<p>Human-centric aspects (Ethical issues, Safety)</p>
	<ul style="list-style-type: none"> • The system must make sure that the human is not identifiable; it must blur the faces of the human • There must be a safety protocol and training • There must be a protocol about who is responsible if there are any accidents in practice • The human must have autonomy in how to execute its job

Example: **Interactive Learning Session for New Hobby Skills (PAL)**



Technical Requirements	<p>1. A robot equipped with the necessary basic skills, including: HRI layer for multimodal interaction; autonomous navigation; object manipulation.</p>
User Interfaces	<p>Natural multi-modal interactions (voice, gestures); optionally, use of an external tablet/smartphone for an additional interaction modality</p>
Use cases	<p>Actor: Robot</p> <p>1. To facilitate an interactive learning session where the user can acquire new skills or hobbies (e.g., cooking a new recipe, doing exercise) with the robot acting as both instructor and assistant, adapting to the user's learning pace and preferences.</p>
Functional Requirements	<ol style="list-style-type: none"> 1. Multimodal Communication: The system must support various forms of communication, including voice commands, gestures, and visual cues. 2. User-Friendly Interface: The robot must feature an interface that is intuitive and easy for non-expert users to navigate for daily tasks and interactions. 3. Safety Mechanisms: The robot must incorporate safety mechanisms to prevent accidents or injuries when interacting with users or navigating the environment. 4. Emergency Detection and Response: The robot must be capable of detecting emergency situations, like falls, and initiating a predefined response protocol, such as alerting family members or emergency services.
Non-functional requirements	<p>Human-centric aspects (Ethical issues, Safety)</p>
	<ul style="list-style-type: none"> • The system must make sure that the human is not identifiable; it must blur the faces of the human • The system must comply with regulation regarding the collection and processing of health data • The system must make sure that it avoids bias • There must be a safety protocol and training • There must be a protocol about who is responsible if there are any accidents in practice • The human must have autonomy in how to execute its job • The robot must not treat humans like objects

Example: Asking for help while carrying medical samples (PAL)



Technical Requirements	1. A robot equipped with the necessary basic skills, including: HRI layer for multimodal interaction; autonomous navigation; object manipulation
User Interfaces	Natural multi-modal interactions (voice, gestures); optionally, use of an external tablet/smartphone for an additional interaction modality
Use cases	Actor: Robot
	<ol style="list-style-type: none"> 1. Monitor request for the staff for object pick-up. 2. Autonomously fetch the object (e.g. medicine) from the hospital pharmacy and deliver it to the nurse requesting it
Functional Requirements	<ol style="list-style-type: none"> 1. Autonomous localisation and navigation in the hospital environment, including operating doors and/or elevator (where required) 2. Optionally, object manipulation (e.g. pick up). Alternatively, this can be performed by a person placed next to the robot. In that case, the robot should be able to request the desired object.
Non-functional requirements	Human-centric aspects (Ethical issues, Safety)
	<ul style="list-style-type: none"> • The system must make sure that the human is not identifiable; it must blur the faces of the human • The system must comply with regulation regarding the collection and processing of health data • The system must make sure that it avoids bias • There must be a safety protocol and training • There must be a protocol about who is responsible if there are any accidents in practice • The human must have autonomy in how to execute its job • The robot must not treat humans like objects <p>1.</p>

Example: Workpiece Holder (POL)	
Technical Requirements	<ol style="list-style-type: none"> 1. Identifying the ergonomics criteria according to operator physical characteristics 2. Communication among human, microphone, cobot and camera
User Interfaces	RVIZ (ROS visualization), Voice command and hand gesture detection.
	Actor: camera

Use cases	<ol style="list-style-type: none"> 1. Extract BGR and depth images of the operator's body including arm, height, neck
	Actor: PC
	<ol style="list-style-type: none"> 1. Extraction of relevant operator's physical parameters to the ergonomics like height, neck and arm length. 2. Calculation of suitable position and orientation of robot's gripper according to the operator's ergonomics 3. Sending the desired trajectory to the robot's controller
	Actor: Collaborative Robot
	<ol style="list-style-type: none"> 1. Holding of the workpiece in the suitable position and orientation 2. Execution of trajectory received from PC
Functional Requirements	Actor: Human workers
	<ol style="list-style-type: none"> 1. Performing the required tasks on the workpiece 2. Orienting the robot's gripper according to his need through a voice command.
	<ol style="list-style-type: none"> 1. There must be a safety button to stop the robot in case of failure or emergency. 2. The operator's voice command me be recognized with the enough accuracy even in the presence of background noises. 3. The camera's field of view and resolution must be such that they allow for the extraction of the required information using image processing tools. 4. Robots must respond to the operator's command promptly.
Non-functional requirements	Human-centric aspects (Ethical issues, Safety)
	<ul style="list-style-type: none"> • The system must make sure that the human is not identifiable; it must blur the faces of the human • There must be a safety protocol and training • There must be a protocol about who is responsible if there are any accidents in practice • The human must have autonomy in how to execute its job

Example: PCB desoldering (POL)											
Technical Requirements	<ol style="list-style-type: none"> 1. Database required for detecting of defective component should be obtained for machine vision. 2. Identifying the proper tool sets for different kind of defects 3. Identifying the ergonomics criteria according to operator physical characteristics 4. Creating the map of working area for the autonomous navigation of AGV 5. Communication between different devices (Control station, Robotic arm, Camera, AGV) 6. Calibration of camera's coordinate with respect to the robot's origin coordinate in workspace 										
User Interfaces	RVIZ (ROS visualization)										
Use cases	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr style="background-color: #e6e6fa;"> <td style="padding: 5px;">Actor: camera</td> </tr> <tr> <td style="padding: 5px;"> <ol style="list-style-type: none"> 1. Extract BGR and depth images of the operator's body including arm, height, neck </td> </tr> <tr style="background-color: #e6e6fa;"> <td style="padding: 5px;">Actor: PC</td> </tr> <tr> <td style="padding: 5px;"> <ol style="list-style-type: none"> 1. Identifying the proper tools and components 2. Coordinate calculation of objects 3. Transformation of acquired coordinate to the robot's coordinate 4. Planning the trajectory of robot to pick and place the objects 5. Send the trajectory to the robot </td> </tr> <tr style="background-color: #e6e6fa;"> <td style="padding: 5px;">Actor: Collaborative Robot</td> </tr> <tr> <td style="padding: 5px;"> <ol style="list-style-type: none"> 1. Execution of planned trajectory </td> </tr> <tr style="background-color: #e6e6fa;"> <td style="padding: 5px;">Actor: Human workers</td> </tr> <tr> <td style="padding: 5px;"> <ol style="list-style-type: none"> 1. Replacing the defective components with the functional ones. </td> </tr> <tr style="background-color: #e6e6fa;"> <td style="padding: 5px;">Actor: AGV</td> </tr> <tr> <td style="padding: 5px;"> <ol style="list-style-type: none"> 1. Transportation of defective PCBs to the reworking stations </td> </tr> </table>	Actor: camera	<ol style="list-style-type: none"> 1. Extract BGR and depth images of the operator's body including arm, height, neck 	Actor: PC	<ol style="list-style-type: none"> 1. Identifying the proper tools and components 2. Coordinate calculation of objects 3. Transformation of acquired coordinate to the robot's coordinate 4. Planning the trajectory of robot to pick and place the objects 5. Send the trajectory to the robot 	Actor: Collaborative Robot	<ol style="list-style-type: none"> 1. Execution of planned trajectory 	Actor: Human workers	<ol style="list-style-type: none"> 1. Replacing the defective components with the functional ones. 	Actor: AGV	<ol style="list-style-type: none"> 1. Transportation of defective PCBs to the reworking stations
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Functional Requirements	<ol style="list-style-type: none"> 1. There must be a safety button to stop the robot in case of failure or emergency. 2. The robot's gripper should be capable of handling objects with high variations in their size and shapes. 										

	<p>3. The camera's field of view, resolution and depth cloud must be such that they allow for the extraction of the object detection and localization.</p> <p>4. The camera's origin coordinate must be calibrated with respect to the robot's base coordinate.</p> <p>5. AGV movement must be fast enough while guarantees the object avoidance in the transportation of PCBs</p>
<p>Non-functional requirements</p>	<p>Human-centric aspects (Ethical issues, Safety)</p>
	<ul style="list-style-type: none"> • The system must make sure that the human is not identifiable; it must blur the faces of the human • There must be a safety protocol and training • There must be a protocol about who is responsible if there are any accidents in practice • The human must have autonomy in how to execute its job