## Summary of Modules

The JARVIS project develops 13 modular technologies to advance human-robot collaboration (HRC) across multiple industries. Their overview is provided below:

### 1. Multi-sensory Perception (MSP)
### Partner: KUKA

The MSP module develops AI algorithms that transform raw sensor data (point clouds, RGB-D images) into structured formats such as 3D meshes and scene graphs. It supports automated camera-to-robot calibration, advanced scene modelling, event and anomaly detection. MSP improves object detection and localisation for reliable grasping and visual inspection. The integration of these perception techniques results in an enhanced human-robot collaboration, increased task efficiency and safety in shared workspaces. Core functionalities of the MSP module include workplace reconstruction, object detection, pose estimation, anomaly detection for quality control and visual inspection.

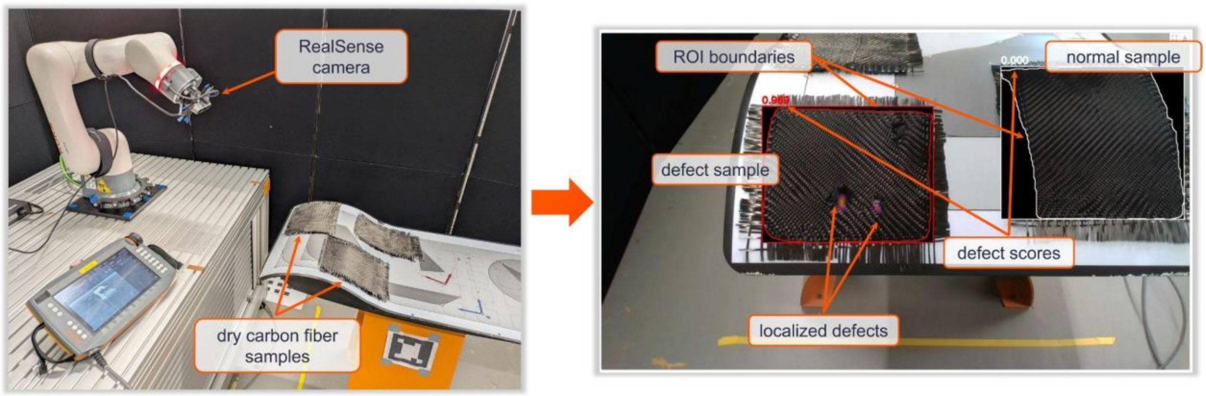


*Fig. 1. COLLINS Visual Inspection*

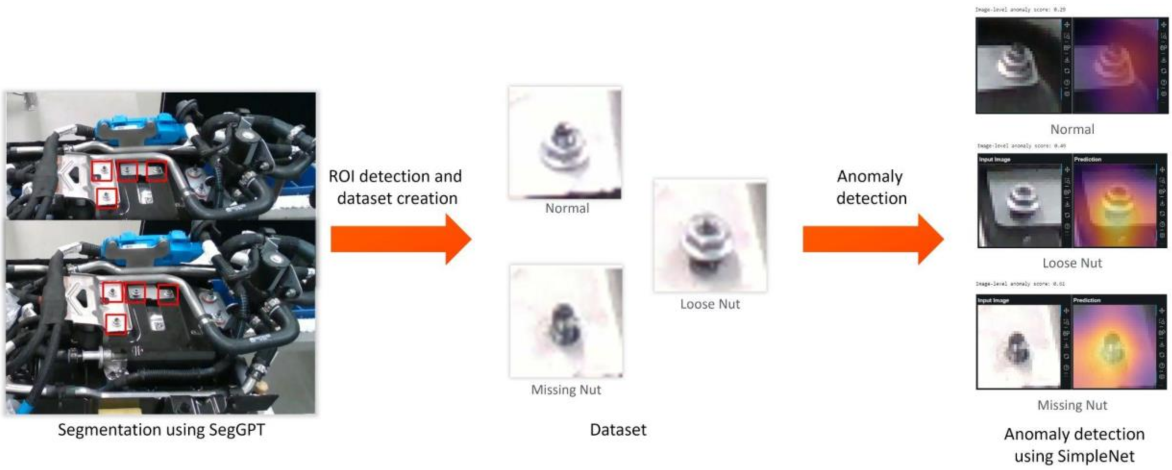


*Fig. 2. TOFAS Visual Inspection*

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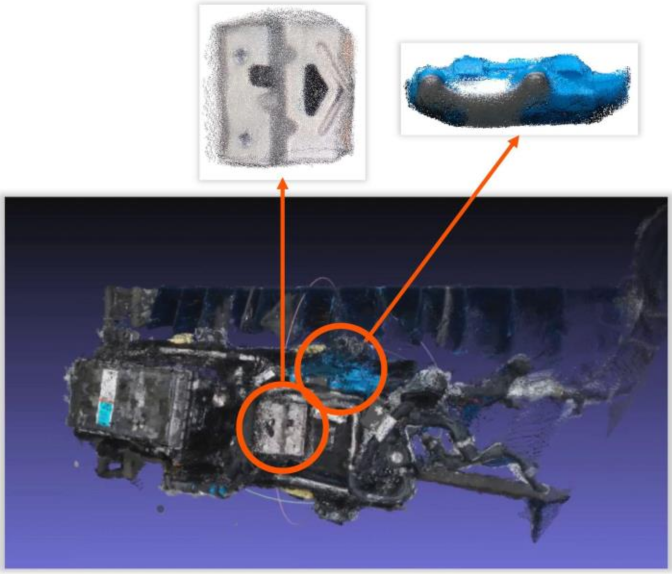

*Fig. 3. TOFAS Reconstructed Battery*

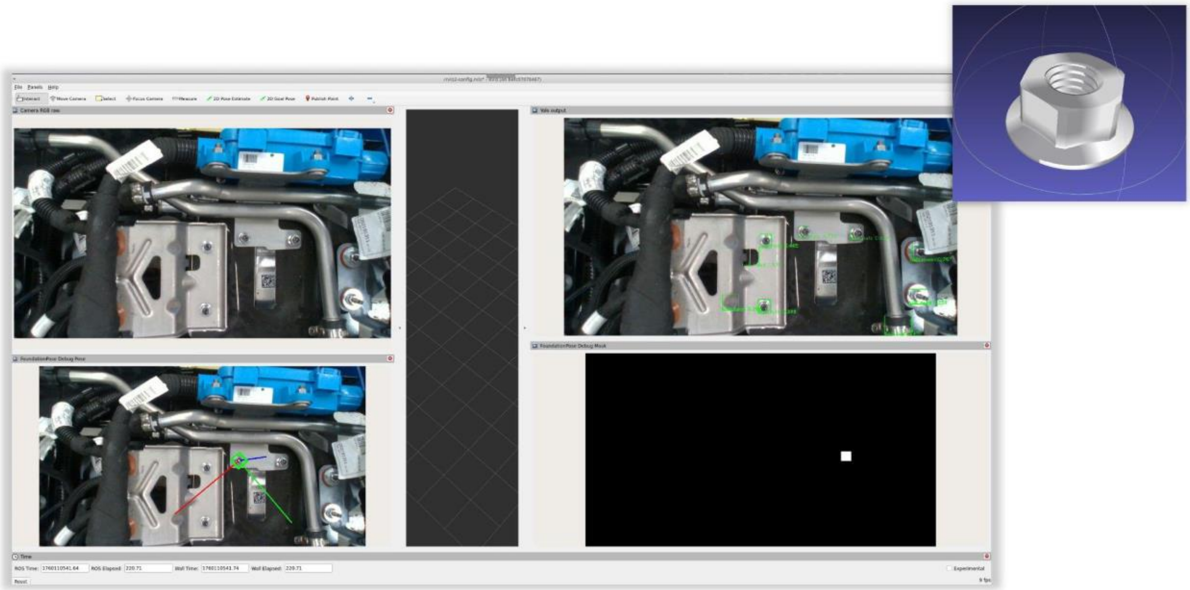

*Fig.4. TOFAS M6 Nut Detection*

## 2. Human Intention Perception and Prediction (HIPAP)

**Partner: COLLINS**

The HIPAP module captures data on process execution and operator behaviour to interpret real-time interactions. Using multimodal inputs from visual and depth sensors combined with AI methods, it identifies and predicts human actions and intent to enable seamless collaboration. HIPAP also integrates environmental data (e.g., CAD models) and semantic

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input from the Intelligent Digital Twin (IDT) to assess the current shopfloor state. During task execution, the same sensory data supports task monitoring, fault detection, and anomaly inspection.

### 3. Intelligent Digital Twin (IDT)
**Partner: CEA**

The IDT module is a modular digital twin framework supporting functionalities such as path planning, virtual guides, and robot simulation. Coupled with the MSP and HIPAP perception modules, IDT provides a dynamic and accurate representation of the system's real-time state, refining initial environment models (e.g., CAD layouts) to reflect reality. It integrates both geometric data (e.g., obstacles) and semantic information (e.g., object types, affordances, possible interactions). Its modular design enables future integration with other JARVIS modules, centralising all relevant data.

### 4. Human Robot Interaction Module (HRIM)
**Partner: LMS**

The Human-Robot Interaction Module (HRIM) enables natural and efficient collaboration between people and robots. It allows operators to interact with robotic systems through voice, gestures, wearables, touch interfaces, or augmented reality, maintaining full control and awareness in real time. Using AR projectors, tablets, screens, or speakers HRIM provides clear task instructions and live process feedback, as needed by the human. Operators can command the robot through voice commands, hand gestures, or physical buttons, and can also query task information, with HRIM acting as an assistant that augments their memory and situational awareness. Its human-centric design and seamless integration of interaction modalities allow the operator to stay focused on the task, ensuring smooth, intuitive, and adaptive collaboration.

### 5. User Centric Interfaces (UCI)
**Partner: TAU**

The UCI module focuses on enhancing the development of user interfaces with improved user experience in mind. This is achieved through an active review and feedback process, and implementation of personalised interfaces. The UCI workflow integrates with interface developers, e.g. those working on Graphical User Interfaces (GUIs), AR/VR, and speech, to develop an intuitive user experience.

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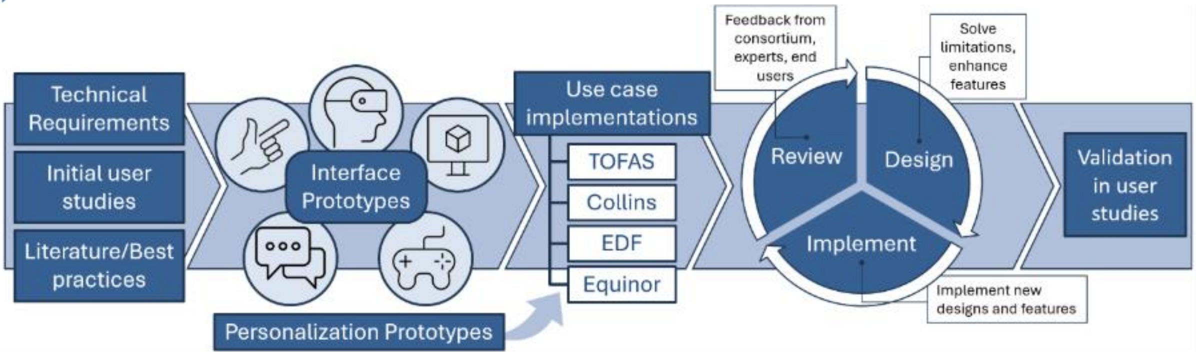


*Fig. 5. UCI Architecture*

## 6. Robot Behaviour Adaptation (ROBA)
**Partner: LMS**

The Robot Behaviour Adaptation Module (ROBA) customizes robot behavior to align with operator preferences and social interaction patterns. Using AI methods such as reinforcement learning, ROBA analyses operator actions, posture, and implicit intent to adapt robot responses in a natural and intuitive way. Through online model training, the robot continuously refines its behavior during task execution without reprogramming, enabling real-time adaptation, smoother collaboration, and a personalized, socially aware working environment.

## 7. Task Planning Module (TPM)
**Partner: LMS**

The Task Planning Module (TPM) can generate optimized work plans for both shared human-robot workspaces and remote cooperation scenarios. It ensures efficient task allocation and prioritization based on environmental factors, task complexity, and operator preferences, adapting dynamically to real-time conditions. Its mixed-initiative planning functionality combines human input with system feedback to improve responsiveness and resource utilization. To further enhance usability, an LLM-based feature (Large Language Model) that enables non-experts to create feasible plans quickly using natural language prompts, process videos, or standard files such as CSV can be optionally used within TPM.

## 8. OpenFlow Orchestrator (OFO)
**Partner: INTRA**

The OFO module manages the interconnection of production resources and software modules, enabling online orchestration, execution, and monitoring of processes. It incorporates interruption recovery mechanisms to ensure resilient execution. Based on task sequences and resource assignments from the Task Planning Module (TPM), OFO issues

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commands to resource controllers and collects feedback on execution status, propagating results to subsequent actions when required.

### 9. Smart Mechatronics Control (SMC)
### Partners: KUKA / TF-CC

The SMC module integrates high-fidelity sensors and adaptive grippers to enable precise execution of complex tasks such as screwing, tube cutting, and delicate part handling. It enables managing gripper commands (e.g., velocity, force, distance) and providing process feedback to operators. Integrated safety sensors ensure compliance with industrial safety standards, enabling reliable and effective human-robot interaction.

### 10. Robot Control Module (RCM)
### Partner: TAU

The RCM module centralises controllers for both mobile robots and robot arms. It supports various motion control modes, including navigation and guidance for mobile robots, trajectory generation for manipulators, and physical interaction controllers such as force and compliance control. It also enables direct teleoperation for user-driven control. By unifying these capabilities in a single module, RCM provides flexible and accessible control options tailored to different tasks and robot types. RCM provides a common interface for all JARVIS modules, ensuring interoperability, scalability, and easier integration across heterogeneous robot systems.

### 11. Generation of Robot Programs (GORP)
### Partner: TECNALIA

The Generation of Robot Programs (GORP) has the goal of developing the usage of generative AI to facilitate robot programming by non-expert users. GORP will produce programs that can then be executed as a sequence of robot skills. These skills can be acquired by other modules or be defined by the GORP itself. This module explores the fusion of language-based semantic reasoning with perceptual grounding and embodied action capabilities. By combining multimodal and physically grounded AI systems, GORP aims to overcome the limitations of purely text-driven models and enable context-aware, safe, and adaptive robot programming by non-expert users.

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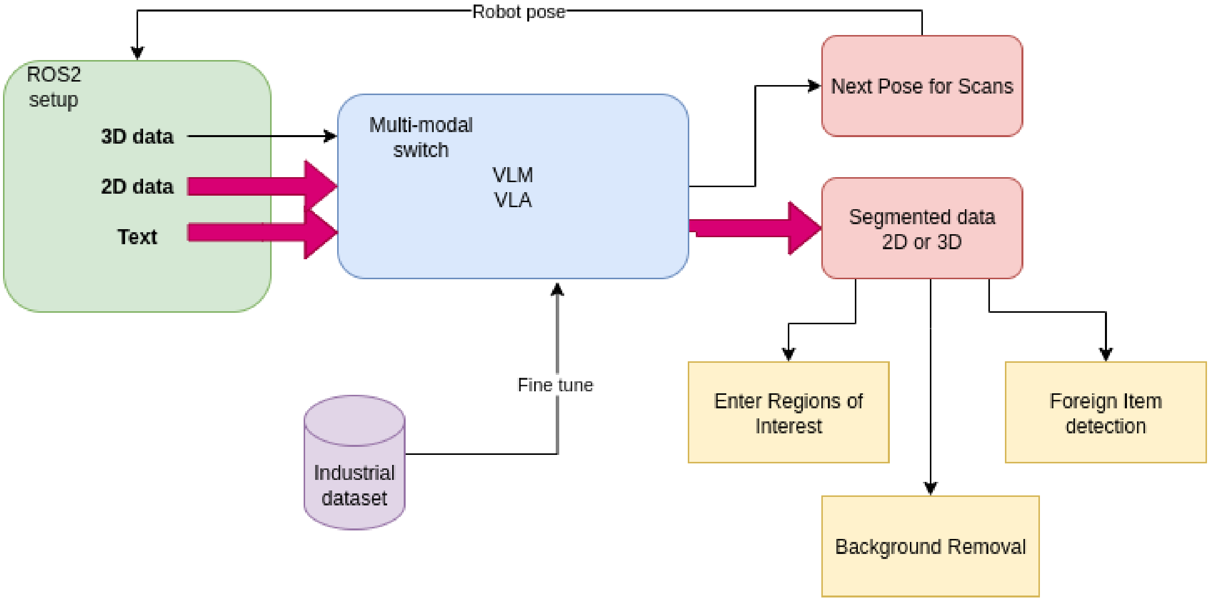


*Fig. 6. GORP Architecture*

## 12. Teaching by Demonstration Module (TDM)
## Partner: TECNALIA

TDM allows operators without programming expertise to teach robots by demonstration. Tasks performed by the operator are captured, enabling the robot to learn and generalise them to similar scenarios (e.g., varying object positions or orientations). Core features include intuitive interfaces, detection and pose estimation, and gesture recognition. This module enables fast task setup and adaptation, increasing flexibility and versatility in collaborative robotics.

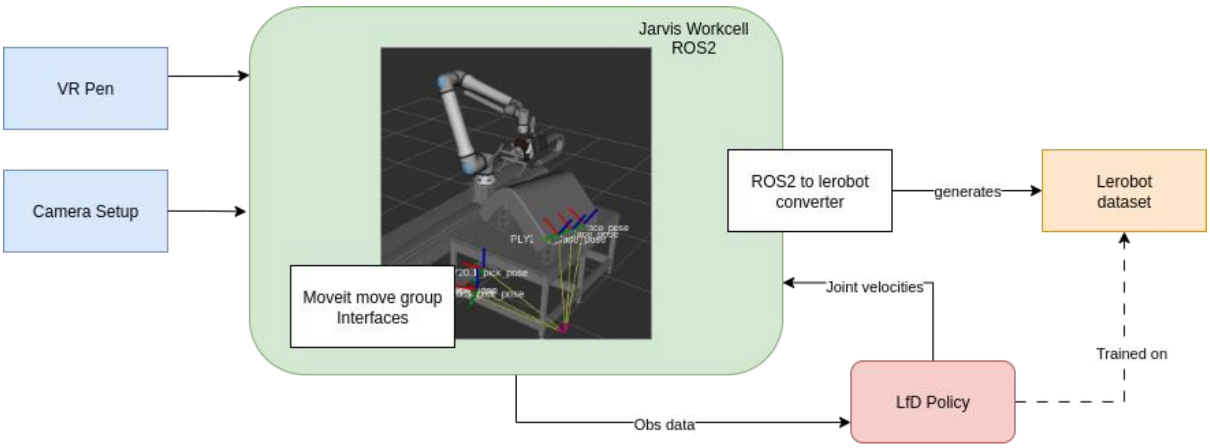


*Fig. 7. TDM Architecture*

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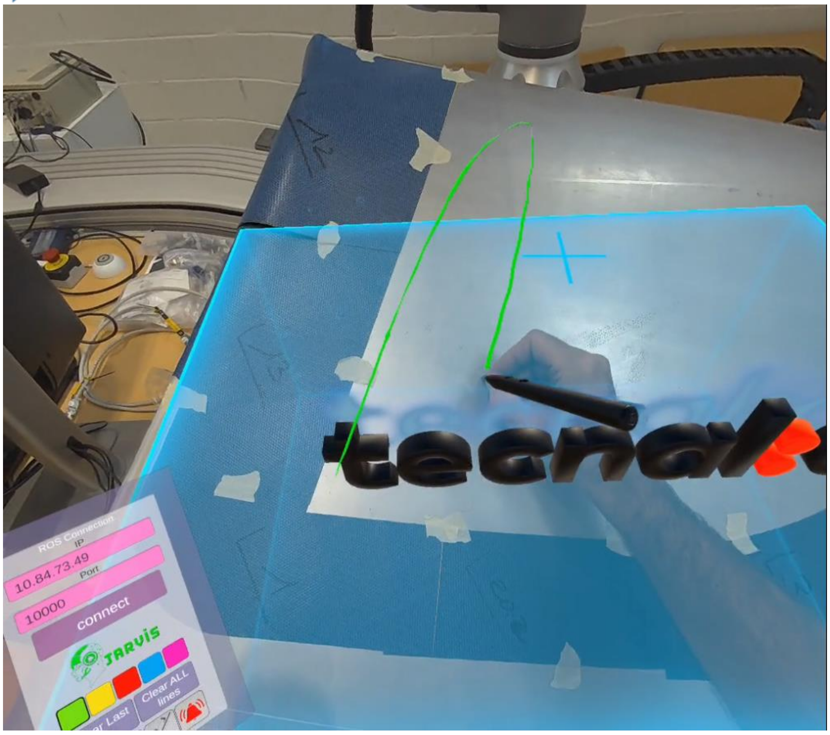


*Fig. 8. TDM Data Capture Process*

**13. Virtual-Reality Teleoperation (VRT)**
**Partner: CEA**

The VRT module combines manual teleoperation, teaching by demonstration, user assistance (e.g., virtual guides), and semi-automated robotic skills. Virtual guides enhance precision and reduce cognitive load, making it easier to define points of interest or trajectories that trigger automated tasks such as cutting, screwing, or inserting. A dedicated GUI and integration with a digital twin improve ergonomics and user experience. VRT supports multiple teaching methods, including motion/force input, teleoperation, and hand-guiding, within a unified multimodal teaching approach.

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