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) into structured formats such as 3D meshes and scene graphs. It supports automated camera-to-robot calibration and advanced scene modelling, event and anomaly detection, and safe navigation. MSP improves object localisation and detection for reliable gripping and visual inspection. By integrating these perception techniques, it enhances human-robot collaboration, increasing efficiency and safety in shared workspaces. Core functionalities include workplace reconstruction, object detection and pose estimation, anomaly and fault detection, workspace monitoring, quality control and visual inspection, and safety and resilience.

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 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 HRIM module facilitates natural collaboration between operators and robots through multimodal interaction. Using augmented reality (via projectors, tablets, or AR glasses), operators receive real-time updates on process status and clear task instructions. Interaction can be performed through voice commands, gestures, or virtual and physical buttons, with adaptability to specific applications. Typical commands such as *"move to point"*, *"pick part"*, or *"skip task"* allow operators to guide the robot naturally, improving efficiency and ease of use.

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5. **User Centric Interfaces (UCI)**

   Partner: TAU

   The UCI module places the operator at the centre of interaction, integrating multiple communication modalities to ensure inclusive and intuitive use even by minimally trained operators. It adapts guidance and feedback to the user's state and preferences, adjusting to experience level, workload, and task context. By combining speech recognition, text-to-speech, and visual recognition of gestures and posture, UCI enhances usability, trust, and operator acceptance in human-robot collaboration.

6. **Robot Behaviour Adaptation (ROBA)**

   Partner: LMS

   ROBA customises robot behaviour to align with operator preferences. By applying AI methods such as reinforcement learning, ROBA analyses operator actions, posture, and preferences to adapt robot responses. Online AI models' training enables the robot to adjust in real time during task execution without the need for reprogramming, ensuring optimal working conditions and fostering a personalised collaborative environment.

7. **Task Planning Module (TPM)**

   Partner: LMS

   TPM coordinates task sequences in shared human-robot workspaces. In more detail, TPM generates, prioritises, and allocates tasks based on different criteria and constraints including environmental factors, task complexity, and operator preferences. It adapts dynamically to real-time production status, reducing idle time and optimising resource use while incorporating operator input.

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 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

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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
    GORP enables non-expert users to create robotic programs through generative AI, in particular large language models (LLMs) that translate natural language instructions into executable robot code. Programs are validated in simulation environments, allowing operators to review and adjust them before deployment. This approach simplifies robot programming while ensuring robust performance in complex industrial tasks.

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.

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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