Skill-based applications in industrial robotics

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***Abstract*— Skill-based production enhances agility and efficiency in modern manufacturing by enabling modularity, interoperability, and dynamic reconfiguration, thereby reducing setup times and operational complexity. This paper presents our developed skill-based applications in industrial robotics for tasks such as sorting, disassembly, machining, and intralogistics.**

I. INTRODUCTION

Skill-based design has long been used in robotics to enhance reusability, modularity, and role separation. A skill encapsulates expert knowledge, such as trajectory planning, and typically operates in lower architecture layers, as in [1], where sequencing layers compose complex behaviors. In dynamic environments, robots require fine-grained skills and flexible composition rather than rigid standard interfaces. For industrial mobile manipulators, tasks, skills, and motion primitives have been defined to establish role separation and skill pre-/postconditions [2]. Rovida et al. extend this concept by defining skills as software blocks that modify world states [3], enabling robots to autonomously sequence skills based on operator-defined goals. These principles are critical for achieving adaptable, efficient, and scalable production systems in modern manufacturing.

This work demonstrates on different robotic applications how skills can be effectively applied in robotics, machining, and intralogistics. These examples will illustrate how skill-based approaches can unlock significant gains in productivity, flexibility, and automation.

II. SKILL-BASED ROBOTICS

Skills are a key element of the Capabilities, Skills and Services (CSS) Model [4], which provides a standardized framework for organizing and utilizing functionalities in industrial systems. While a Capability is an abstract and implementation-independent specification of an automation function, a Skill is the executable realization of such a Capability. In addition, Services are more on the business level in the context of a digital marketplace. However, this paper focuses specifically on the concept of skills.

Each skill is accessed and controlled via a standardized skill interface, which is typically implemented using OPC UA (Open Platform Communications Unified Architecture). OPC UA provides a vendor-neutral framework for communication and ensures that skills are accessible in a consistent and interoperable manner across different systems. Through the skill interface, users can control the skill's state machine, monitor its execution, and transfer necessary parameters [5].

In modern manufacturing systems, skills are fundamental to enabling flexibility and responsiveness. They are employed to manage and automate complex tasks by dividing the process into three key phases [6], [7]:

- **FeasibilityCheck:** This phase determines whether a skill can be executed under the given parameters. It often involves simulations, calculations, or analyses to ensure the task is viable.
- **PreconditionCheck:** This phase verifies that all necessary conditions for skill execution, such as the availability of tools or resources, are met.
- **SkillExecution:** During this phase, the actual task is carried out. Data generated during execution, such as performance metrics, is recorded to improve future operations.

The versatility and modularity of skills make them invaluable across a range of manufacturing domains.

A. Pick-and-Place Tasks

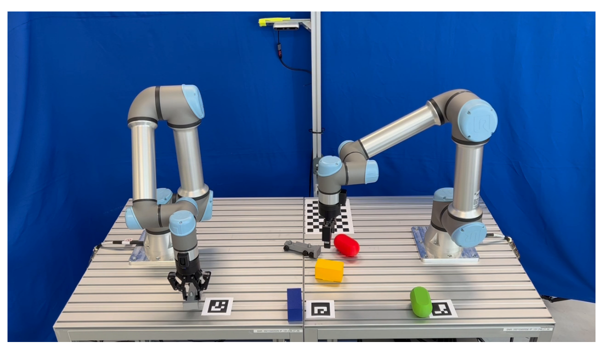

Fig. 1. Autonomous sorting of objects by two manipulators sharing a common workspace [8].

Pick-and-place tasks, implemented as skills, enable assembly, disassembly, and sorting. Autonomous execution by multiple manipulators requires coordination and collision-free interaction, achieved through a combination of atomic and composite skills. Figure 1 illustrates cooperative sorting of toy truck components by two manipulators executing tasks simultaneously. Task distribution is optimized using a mixed-integer bilinear programming approach [9], while trajectories are planned and executed online via distributed model

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predictive control with integrated collision avoidance [10]. Potential deadlocks during execution are reliably detected by each robot and resolved by a supervisory instance [10].

B. Machining

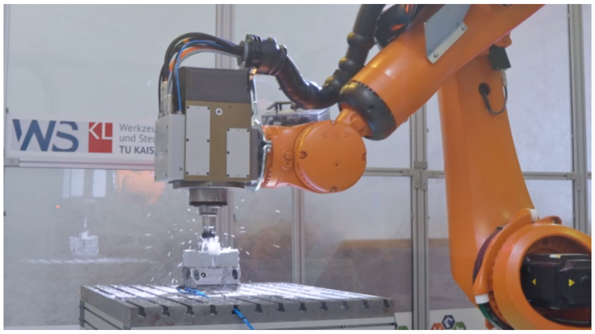

Fig. 2. Skill-based milling using an industrial robot and attached milling spindle

Our work in skill-based machining focuses on the direct production of individualized components by seamlessly integrating feature extraction from CAD models with modular skill execution. The goal was to eliminate traditional steps like CAM programming and G-code generation, reducing complexity and setup times [11].

We have developed a specialized CAD plug-in that extracts key geometric features such as holes, pockets, and slots, along with material and tolerance data, directly from the CAD model. Capabilities are then used to map these features to specific manufacturing skills. These manufacturing skills are provided with a standardized OPC UA-based skill interface. The skill encapsulates the complexity of its machining processes behind its interface. Fig. 2 shows our robotic cell with a milling spindle, where tasks such as tool selection, path planning, and process control are handled autonomously within the skill [12], [7].

C. Intralogistics

By modeling transport and storage processes through capabilities, skills, and services, the CSS model standardizes logistics tasks. Transport systems, such as Automated Guided Vehicles (AGVs), Autonomous Mobile Robots (AMRs), see Fig. 3, and conveyors, provide capabilities like transporting goods, executing handovers, and managing storage. These are encapsulated as skills that can be orchestrated dynamically based on production demands, enabling adaptive transport planning instead of static logistics routes. [13]

The implemented skill set includes:

- GetTransporter – for reserving and scheduling a transport system
- ReleaseTransporter – for making the transport system available for new tasks
- Store and Deplete – for managing warehouse operation
- Charge – for handling energy management of mobile transport systems

These are exemplary; additional skills exist for other logistics functions. The use of ROS2 and OPC UA ensures scalability and interoperability, reducing vendor lock-in and enabling modular transport fleet expansion. Integrating skill-based transport planning with OPC UA-based Asset Administration Shells (AAS) provides a standardized approach to managing transport tasks across heterogeneous systems. [13]

Fig. 3. Autonomous Mobile Robot for developing skills in intralogistics

III. CONCLUSIONS

This work demonstrates how skill-based approach enhances efficiency, supports individualized production in industrial robotic applications, and reduces reliance on manual intervention, aligning with the principles of Industry 4.0.

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