Industrial Applications of Collaborative Robots- a case study

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Abstract:

The rapid transformation of global manufacturing, characterized by increasing product variety, shorter production cycles, and growing emphasis on human–centric operations, has accelerated the adoption of collaborative robots (cobots). Unlike traditional industrial robots confined to fenced environments, cobots are designed to safely share workspaces with human operators through power-and-force limiting mechanisms, advanced sensing, and intuitive programming. This paper provides a comprehensive review of the industrial applications of cobots across major sectors, including automotive, electronics, packaging, food processing, pharmaceuticals, metalworking, logistics, and consumer goods. The study highlights the advantages of cobots—flexibility, safety, precision, and cost-effectiveness—and discusses their role in augmenting human capabilities. Emerging trends, challenges, and future opportunities for cobot deployment are also outlined.

Keywords: Collaborative robots, Cobots, Human–robot collaboration (HRC), Industry 4.0, Industry 5.0, Flexible automation, Manufacturing systems

1. Introduction

The evolution of robotics from fully automated, isolated industrial robots to collaborative robots (cobots) represents a significant paradigm shift in modern manufacturing [18]. Cobots are engineered to work safely alongside human workers without the need for physical barriers, fostering a hybrid workspace where human dexterity and robot precision complement each other. Their compact structure, low implementation cost, and ease of programming have made them accessible to both large industries and small and medium enterprises (SMEs) [19].

As manufacturing transitions towards smart, adaptive, and human-centric paradigms under Industry 4.0 and Industry 5.0, cobots serve as key enablers of flexibility and personalization [1], [16]. This paper systematically reviews the major industrial applications of cobots and analyses how they enhance productivity, ergonomics, and operational efficiency.

2. Industrial Applications of Collaborative Robots:

Cobots are increasingly deployed across major industrial sectors owing to their flexibility, programmability, and capability to handle variable tasks [17], [18]. Table 1 summarizes critical applications and associated technical requirements.

Table 1. Sector-wise Applications and Requirements of Cobots

Industry	Key Applications	Critical Requirements
Electronics Manufacturing [4], [12]	• PCB insertion & placement • Soldering and dispensing • Connector assembly & cable routing • Functional testing & inspection • Precision screwdriving • ESD-safe component handling	• High precision (±0.05 mm) • ESD-safe materials & grounding • Cleanroom compatibility • Vision-guided alignment • Force-torque sensing • Traceability & data logging
Food & Beverage [3], [17]	• Primary packaging (tray loading, bottle placement) • Pick-and-place of bakery & confectionery items • Case packing & cartooning • Palletizing • Quality inspection (seal, weight) • Labelling & date coding	• Food-grade materials • IP65/IP67 washdown protection • Easy sanitation • Temperature tolerance • Gentle handling • HACCP compliance
Pharmaceutical & Medical Devices [4], [17]	• Vial/ampoule handling • Blister pack assembly & inspection • Syringe assembly & filling support • Serialization & packaging • Laboratory automation • Medical device assembly	• Cleanroom (ISO 5–8) • Process validation • Serialization & traceability • Contamination-free operation • 21 CFR Part 11 compliance • Audit trail generation
Automotive [5], [20]	• Interior component installation • Wire harness routing • Screwdriving & fastening • Adhesive/sealant dispensing • Quality inspection • Parts kitting/presentation	• Integration with existing automation • Multi-shift reliability • Handling variable part sizes • Safe human–robot coordination • Tool-changing capability • MES/ERP data integration
Consumer Goods & E-Commerce [13], [15]	• Order picking & kitting • Multi-SKU packaging • Labeling & shipping preparation • Quality inspection • Returns processing • Customized packaging & gift wrapping	• Rapid SKU changeover • Vision-guided picking • WMS integration • Product diversity handling • High throughput scalability • Easy reconfiguration for campaigns

3. Enabling Technology and Standards Used in Cobots:

The rapid adoption of cobots across manufacturing environments is fuelled by advances in sensing, control, software interoperability, and digital technologies [16], [21]. These technologies collectively enable cobots to operate safely, adapt to dynamic conditions, and collaborate intelligently with human workers.

3.1 Key Enabling Technologies

Technology Category	Key Contributions
Advanced Sensing [16]	Perception, safety, dexterity
AI & ML [16]	Adaptation, decision-making, prediction
HMIs	Intuitive interaction, easy programming
ROS/Middleware	Interoperability, modular control
Advanced End-Effectors	Versatility, precision handling
Cloud/IoT [1]	Monitoring, optimization, scalability
Digital Twin [1], [21]	Simulation, planning, predictive control
CPS [1]	Real-time synchronization and coordination
AMRs/Mobile Cobots	Flexibility, dynamic workflows
Safety Technologies [11], [14]	Human protection, compliance

Table 2. Key Enabling Technologies

3.2 Major Safety Standards Governing Cobots

Standard	Scope	Key Provisions
ISO 10218-1 [6]	Robot safety requirements	General safety requirements for industrial robots
ISO 10218-2 [7]	Robot system integration	Requirements for robot system integration and safe operation
ISO/TS 15066 [2], [8], [11]	Collaborative robots	Specific guidance on four types of collaborative operation, force/pressure limits for 29 body regions
ISO 13849 [10]	Safety control systems	Requirements for safety-related control systems
ISO 12100 [9]	Risk assessment	General principles for design and risk assessment

These standards collectively guide manufacturers in designing, implementing, validating, and safely operating human–robot collaborative systems [2], [11], [14].

4. Key Challenges in Collaborative Robots (Cobots):

Despite their growing potential, cobots face several operational and implementation challenges [13], [18], [19]

Table 3. Challenges Associated with Cobots

Challenge Category	Description / Issues
1. Safety & HRC Limitations [8], [14]	• Restricted speed and payload to meet safety standards (ISO/TS 15066) • Risk of unintended collisions • Limited effectiveness of sensors in dynamic human environments • Continuous safety assessment required
2. Low Payload & Speed [19]	• Cobots typically handle 3–20 kg, unsuitable for heavy-duty tasks • Slower than industrial robots to ensure safe human interaction • Reduced cycle times impact productivity
3. Integration with Legacy Systems [18]	• Difficulty interfacing with old machines, PLCs, and conveyors • Lack of standardized communication protocols • Requires custom integration or middleware
4. Programming & Skill Requirements [13]	• Complex tasks need advanced coding skills • Vision and force-control programming increases difficulty • Shortage of trained personnel in HRC task design
5. End-Effector & Tooling Limitations	• Standard grippers struggle with complex or deformable objects • Custom tooling raises cost and development time • Limited tool-change speed for multi-operation cells
6. Sensing & Perception Challenges [16]	• Vision issues with reflective, transparent, or soft objects • Sensitivity to lighting variations • Inaccurate detection can cause safety or quality issues
7. Cost & ROI Uncertainty [13], [19]	• Initial investment rises due to tooling, sensors, integration • ROI decreases for highly variable tasks • Hidden costs in training and maintenance
8. Regulatory & Standards Compliance [6], [7], [8]	• Must adhere to ISO 10218, ISO/TS 15066, GMP, HACCP • Compliance requires documentation, validation, and audits • Slows down deployment in regulated industries
9. Workspace & Layout Constraints	• Limited reach restricts placement options • Need optimized path planning in shared environments • Possible bottlenecks in human–cobot zones

5. Conclusion

Collaborative robots have emerged as a transformative technology in modern manufacturing, enabling safe, flexible, and human-centric automation across diverse industrial sectors. As demonstrated through the reviewed applications—from electronics assembly and automotive manufacturing to food processing, pharmaceuticals, logistics, and consumer goods—cobots play a pivotal role in bridging the gap between manual and fully automated operations [4], [12], [17]. Their ability to operate beside human workers, adapt to dynamic production requirements, and perform precision-driven tasks makes them indispensable in high-mix, low-volume, and rapidly changing environments [19].

The integration of enabling technologies such as advanced sensing, machine learning, intuitive HMIs, mobile robotics, and digital twins has significantly expanded the functional capabilities of cobots [16], [21]. These advancements not only enhance safety and interoperability but also support predictive planning, real-time decision-making, and scalable automation aligned with Industry 4.0 and Industry 5.0 principles [1], [16]. Additionally, internationally recognized safety standards—such as ISO 10218 and ISO/TS 15066—provide essential frameworks for ensuring risk-free human–robot collaboration [2], [8], [11], [14].

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