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Human-Robot Collaboration in Industries

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Abstract- Human-Robot Collaboration (HRC) has emerged as a foundational paradigm of the fourth industrial revolution (Industry 4.0), enabling seamless integration of human cognitive capabilities with robotic precision, strength, and repeatability within shared workspaces. This paper presents a comprehen- sive survey of HRC in industrial environments, synthesizing recent advances across sensor-based perception, safety control techniques, collaborative robot (cobot) design, and workforce competency requirements. Drawing from an analysis of fifteen key studies spanning assembly, manufacturing, construction, and smart factories, we examine the classification of HRC interaction modes—coexistence, synchronization, cooperation, and collaboration—alongside critical enabling technologies including deep learning-based visual perception, motion planning, collision avoidance, ergonomics-oriented control, and digital twins. A structured literature review table, comparative analysis, and key findings discussion are presented. The paper identifies persistent challenges in data collection, model reliability, safety assurance, and human competency alignment, while highlighting promising research directions toward Industry 5.0, where human-centric collaboration becomes the central focus.

Index Terms—Human-Robot Collaboration, Collaborative Robots, Industry 4.0, Safety Control, Visual Perception, Ergonomics, Smart Manufacturing, Deep Learning, Industry 5.0

I. INTRODUCTION

The fourth industrial revolution, commonly referred to as Industry 4.0, has fundamentally transformed how humans and machines interact on the factory floor. Central to this transfor- mation is the concept of Human-Robot Collaboration (HRC), wherein collaborative robots—or cobots—are deployed to work alongside human operators in shared workspaces, com- bining the complementary strengths of both. While traditional industrial robots operated in fenced-off cells to ensure oper- ator safety, modern cobots are designed to function without physical barriers, sensing and reacting to human presence in real time [1].

Humans excel in adaptability, creativity, dexterous manipulation, and complex decision-making, while robots offer superior precision, repeatability, strength, and tirelessness. By combining these complementary attributes, HRC systems can achieve levels of productivity, flexibility, and quality that neither humans nor robots could attain independently [2]. Industries from automotive assembly to food processing, from construction to healthcare, are increasingly adopting HRC to address growing demands for customization, labor efficiency, and operational safety [3].

Research in HRC has expanded rapidly since 2015, driven by advances in sensing, machine learning, and cobot hardware. The collaborative robot market is projected to reach $2 billion by 2030, reflecting the significant industrial interest in this paradigm [6]. Simultaneously, visionaries are looking beyond Industry 4.0 toward Industry 5.0, which places humans back at the center of the automation chain, making HRC an even more critical area of study [5].

Despite this growth, key challenges persist: safely sharing workspaces, ensuring ergonomic well-being, maintain- ing productivity, and equipping the workforce with relevant competencies. Organizational human factors are frequently overlooked despite being as critical as engineering challenges

for successful HRC deployment [10]. Trust, acceptance, and worker confidence in fenceless robotic environments remain underexplored [8].

This paper presents a comprehensive survey of HRC in industrial environments. Our contributions are: (1) a systematic taxonomy of HRC interaction modes; (2) a structured literature review of 15 key studies; (3) a comparative analysis of method- ologies and findings; (4) a review of control, perception, and scheduling techniques; (5) a synthesis of results and identified research gaps; and (6) future directions aligned with Industry

5.0. The paper is organized as follows. Section II covers HRC concepts. Section III presents the literature review. Section IV describes methodologies. Section V provides comparative analysis. Section VI discusses results. Section VII concludes.

II. HUMAN-ROBOT COLLABORATION: CONCEPTS AND CLASSIFICATION

The terms human-robot interaction (HRI) and human-robot collaboration (HRC) are frequently confused. Interaction de- scribes any reciprocal influence between two entities without requiring a common goal, while collaboration denotes joint work toward a shared objective [2]. In industrial HRC, a human operator and a robot form a tightly coupled dynamic system to perform a manufacturing task [8].

A. Types of HRC Interaction

Four primary interaction modes are distinguished in the literature, ordered by degree of coupling [3], [9]:

- Coexistence: Agents share a facility but work on distinct tasks without intersecting workspaces.
- Synchronization: Agents share the workspace and coor- dinate actions sequentially on the same target at different times.
- Cooperation: Agents share resources and may overlap workspaces but pursue independent sub-goals.
- Collaboration: Agents work together simultaneously on the same task with direct contact possible.

B. Structural Components of HRC Systems

An HRC system involves four design dimensions: collabo- ration levels, work roles, safety control modes, and commu- nication interfaces [8]. Safety control modes are standardized by ISO 10218 and ISO/TS 15066, covering safety-monitored stop, hand guiding, speed and separation monitoring (SSM), and power and force limiting (PFL). Communication interfaces have evolved beyond teach pendants to encompass gestures, eye tracking, voice commands, and haptic feedback [9].

C. Cobots: The Hardware Backbone

Unlike traditional caged robots, cobots feature small form factors, built-in force-torque sensing, rounded edges, and safety-rated limits allowing fenceless operation [6]. Leading platforms include Universal Robots UR series, Franka Emika Panda, ABB YuMi, and KUKA LBR iiwa. These can be programmed by non-expert operators via hand guiding or demonstration-based learning, reducing deployment times substantially [1].

III. LITERATURE REVIEW

A. Overview of Reviewed Studies

A structured review of fifteen key contributions to HRC re- search is presented in Table I. Studies were selected to span the major dimensions of HRC research: perception and sensing, control techniques, safety, ergonomics, efficiency, workforce competencies, and industrial applications. The review covers publications from 2015 to 2026, sourced from IEEE, Procedia, IET, Frontiers, and domain-specific journals.

B. Thematic Discussion of Literature

Sensor-Based Perception (Study 1): Angleraud et al.

[1] demonstrate that deep learning visual perception models, deployed via the OpenDR toolkit within a ROS framework, can perform real-time skeletal tracking and gesture detection sufficiently for industrial HRC. However, high latency in external sensors remains a critical barrier to seamless fluency, particularly in noisy manufacturing environments with metal- lic reflections, occlusions, and variable lighting. Their work highlights the gap between laboratory-grade perception and factory-ready deployment.

HRC and Industrial Transformation (Studies 2, 3, 6): Baratta et al. [2] use bibliometric analysis to identify how HRC is transitioning from an Industry 4.0 enabler to the central pillar of Industry 5.0. Othman and Yang [3] reinforce this through case studies showing HRC reduces material waste and improves task stability, particularly in automotive and food production. Raffik et al. [6] emphasize that cobots are essential for achieving mass customization, though full physical-virtual integration is still an ongoing challenge.

Safety, Interaction, and Trust (Studies 8, 9, 11): Maurtua et al. [8] demonstrate through the FourByThree project that worker trust is primarily built through safety assurance and natural multimodal interaction. Vysocky and Novak [9] show that shared workspaces can delegate non-ergonomic tasks to robots but note that advanced sensor readiness is a limiting factor. Robla-Go´mez et al. [11] provide a comprehensive review of collision avoidance systems, concluding that re- pulsive vector methods effectively prevent collisions, though productivity trade-offs remain.

Control Techniques (Studies 5, 15): Proia et al. [5],
[15] provide the most extensive survey of HRC control, categorizing 120 papers by safety, ergonomics, and efficiency targets. Their analysis reveals that approximately 59% of literature focuses on safety, 18% on ergonomics, and 23% on efficiency, and that only 12% of papers address dual targets while none simultaneously optimize all three. Real-time multi-target optimization is identified as a critical unsolved problem. Workforce Competencies (Studies 4, 7, 14): Three Delphi- based studies by Olukanni et al. [4], [7], [14] examine HRC competency requirements in the construction sector. All three consistently identify knowledge of human-robot interfaces, safety standards, and task planning as the most critical competencies. Notably, academia prioritizes ethics and regulatory knowledge while industry focuses on operational skills, revealing a persistent curriculum alignment gap.

Organizational Human Factors (Studies 10, 13): Charalambous et al. [10], [13] argue through exploratory qualitative research that organizational human factors—including change management, workforce training, and culture—are equally critical to successful HRC implementation as any technical engineering challenge. Their work highlights the absence of formal frameworks for addressing these factors, a gap that remains largely unaddressed in the robotics literature.
Lab-to-Industry Transition (Study 12): Doulgeri and Dimeas [12] synthesize outcomes from the CoLLaboratE project and ICRA workshop contributions to identify the steps required to transition HRC systems from laboratory research to industrial adoption. Key barriers include the need for genuine, adaptive, and gentle interaction models that function robustly under real-world variability.

IV. METHODOLOGIES USED IN HRC RESEARCH

The reviewed literature employs a diverse set of research methodologies, broadly classifiable into four categories.

A. Deep Learning and Perception-Based Methods

Studies employing deep neural networks for visual perception dominate the sensor-based HRC literature. Skeleton detection using lightweight OpenPose achieves 30 frames per second at full HD with over 91% accuracy [1]. The ST- GCN framework processes spatial-temporal skeleton graphs for action recognition across 60+ classes. Object and target detection using Mask R-CNN with custom-augmented datasets of 280,000 images achieves over 93% detection accuracy at 2.6–6 fps. These methods are implemented within the ROS middleware framework and the OpenDR toolkit, which provides standardized interfaces for deploying deep learning models in robotics applications.

B. Control and Optimization Methods

Safety-oriented control techniques include Speed and Sepa- ration Monitoring (SSM), Power and Force Limiting (PFL), and the more rigorous Control Barrier Functions (CBFs), which provide optimization-based guarantees compatible with ISO/TS 15066 [5]. Nonlinear Model Predictive Control (NMPC) is used for minimum-time trajectory planning un- der safety constraints. For ergonomics, Mixed-Integer Linear Programming (MILP) schedulers allocate tasks to minimize makespan and musculoskeletal risk simultaneously. Reinforce- ment Learning (RL) is applied for adaptive task sequenc- ing. Impedance and admittance controllers manage compliant physical interaction, with energy-tank-based variants ensuring passivity and stability [11].

C. Expert Survey and Delphi Methods

Multiple studies employ the Delphi methodology—a struc- tured, iterative expert elicitation technique—to identify and prioritize HRC competencies. Olukanni et al. [4], [7], [14] conduct two- and three-round Delphi studies with separate industry and academic expert panels in the construction sector. Charalambous et al. [10], [13] use qualitative exploratory research to develop theoretical human factors frameworks. These social-science methods complement the engineering lit- erature by capturing practitioner knowledge that is not readily codifiable in technical standards.

D. Bibliometric and Systematic Literature Review

Baratta et al. [2] apply bibliometric analysis to map the HRC research landscape, identifying publication trends, co- authorship networks, and keyword clusters. Proia et al. [5],

[15] conduct a systematic review of 120 papers from IEEE Xplore, Science Direct, and Scopus, categorizing contributions by target (safety, ergonomics, efficiency) and control type. These meta-analytical methods provide a macro-level view of the field and are particularly valuable for identifying research gaps and emerging directions.

V. COMPARATIVE ANALYSIS

A. Research Focus Distribution

Table II presents a comparative analysis of the fifteen reviewed studies across six dimensions: primary target (safety / ergonomics / efficiency / competencies / perception / orga- nizational), methodology type, industrial domain, whether the study proposes new technology or reviews existing work, and whether it identifies research gaps.

B. Safety vs. Ergonomics vs. Efficiency

A consistent finding across the reviewed literature is the asymmetric distribution of research effort. Safety dominates, with approximately 59% of surveyed control papers addressing it, compared to 23% for efficiency and only 18% for er- gonomics [5], [15]. Collision avoidance and detection together account for roughly 44% of safety papers, while trajectory planning represents approximately 31%. This imbalance re- flects the primacy of regulatory requirements (ISO/TS 15066) and liability concerns in industrial deployments.

Ergonomics, particularly cognitive ergonomics, remains un- derexplored despite the fact that work-related musculoskeletal disorders (MSDs) affect nearly 50% of workers in devel- oped nations. Scheduling-based ergonomic optimization using MILP and Petri net frameworks shows promise but is rarely combined with real-time safety control [5]. Efficiency-focused contributions, particularly those using reinforcement learning and digital twin frameworks, have grown significantly since 2019, reflecting the increasing commercial pressure to justify HRC investments.

C. Technical vs. Organizational Perspectives

Most HRC research adopts a purely technical perspective— designing better sensors, controllers, or planners. Only a minority of works, notably Charalambous et al. [10], [13] and the Olukanni et al. Delphi series [4], [7], [14], address the organizational and workforce dimensions of HRC deployment. This represents a significant blind spot: even a technically perfect cobot will fail if workers distrust it, if managers resist organizational change, or if training programs do not equip operators with the right competencies.

Table I
Literature Review Summary Of Key Hrc Studies

No.	Author(s) & Year	Problem Addressed	Methodology	Key Findings	Research Gap
1	Angleraud et al. (2024) [1]	Fluent HRC in noisy industrial environments	Deep learning visual perception; ROS; OpenDR	Real-time skeletal and gesture tracking is feasible	High sensor latency limits performance
2	Baratta et al. (2023) [2]	Unclear HRC paradigms bridging I4.0 and I5.0	Bibliometric analysis	Core HRC research trends identified	I5.0 paradigms remain undefined
3	Othman & Yang (2022) [3]	Adaptive HRC to reduce manual labor	Literature review; automotive/food case studies	HRC reduces waste and stabilizes high-accuracy tasks	Challenges for mass customization persist
4	Olukanni et al. (2025a) [4]	Skill gaps between industry and academia in construction	3-round Delphi study	Safety, standards, robot control are top knowledge areas	Academia/industry curriculum alignment needed
5	Proia et al. (2022) [5]	Balancing safety, ergonomics, efficiency in HRC control	Categorized review; MILP optimization	Few studies jointly optimize all three targets	Real-time multi-target optimization is computationally burdensome
6	Raffik R. et al. (2023) [6]	Mass production to mass customization transition	Review of I5.0 and cobot evolution	Cobots enhance productivity via labor sharing	Physical-virtual world integration remains a hurdle
7	Olukanni et al. (2025b) [7]	Industry perspectives on HRC competencies in construction	2-round Delphi; US expert panel	HRC safety, interface knowledge, task planning are critical	Sector-specific competency research is limited
8	Maurtua et al. (2017) [8]	Worker trust in fenceless	FourByThree project	Safety and natural interaction drive	Complex tasks remain too

		environments	experiments	HRC adoption	expensive to automate
9	Vysocky & Novak (2016) [9]	Safety restrictions in shared workspaces	Technical review of MRK; I4.0 standards	Shared workspaces enable delegation of non-ergonomic tasks	Sensor readiness for real-time monitoring is a bottleneck
10	Charalambous et al. (2015) [10]	Neglected organizational human factors in HRC	Exploratory human factors framework study	Organizational factors are as critical as engineering	No established HRC organizational frameworks exist
11	Robla-Go´mez et al. (2017) [11]	Rigid workspace separation limiting productivity	Multidisciplinary safety and collision avoidance review	Repulsive vectors effectively prevent collisions	Productivity-safety trade-offs remain difficult to balance
12	Doulgeri & Dimeas (2026) [12]	Lab-to-industry transition gap	CoLLaboratE project; ICRA workshop	Identifies transition steps toward industrial HRC adoption	Genuine adaptive interaction models are still immature
13	Charalambous et al. (2015) [13]	Human element barriers to HRC implementation	Theoretical human factors framework	Org. factors are as critical as engineering for HRC success	No sector-specific organizational HRC frameworks
14	Olukanni et al. (2025c) [14]	Construction-specific HRC competency gaps	2-round Delphi; US industry expert panel	Interface knowledge, safety standards, and task planning are most critical	Industry prioritizes operations over long-term ethics
15	Proia et al. (2022) [15]	Simultaneous control of safety, ergonomics, efficiency	Categorized control literature review	Safety is most studied; simultaneous multi-target studies are very few	Computational complexity limits real-time multi-target control

D. Industry vs. Academia: Competency Perception Gap

The three Delphi studies by Olukanni et al. reveal a consistent pattern: industry professionals prioritize practical, operational competencies—task planning, technical operation, safety management—while academics emphasize theoretical foundations and ethical-regulatory knowledge. Specifically, HRC ethics and regulation is ranked 4th by academics but only 18th by industry experts. This gap has direct implications for curriculum design in engineering and vocational education programs, where industry-aligned content must be balanced with the broader societal perspective that academia contributes [4], [7], [14].

E. Perception Model Comparison

Table III compares the key deep learning perception modules employed in HRC systems. The lightweight

OpenPose model achieves real-time performance (30 fps) with high accuracy, making it suitable for human presence monitoring. Action recognition with ST-GCN operates at 20–30 fps but requires a minimum of 300 frames for reliable classification, introducing latency for rapid motion changes. Object detection with Mask R-CNN is accurate (93%) but slower (2.6–6 fps), which may be insufficient for high-speed assembly. 3D pose estimation with VoxelPose requires multiple synchronized cameras, increasing infrastructure cost. Gesture recognition with CNN and depth sensing offers high accuracy (85–95%) at low cost.

VI. RESULTS AND DISCUSSION

A. Key Findings from the Literature

The synthesis of fifteen reviewed studies yields the following principal findings:

Table II
Comparative Analysis Of Reviewed Hrc Studies

Ref.	Primary Focus	Method Type	Domain	New Tech?
[1]	Perception	Experimental	Manufacturing	Yes
[2]	I4.0/I5.0 trends	Bibliometric	General	No
[3]	Smart manufacturing	Review	Auto/Food	No
[4]	Competencies	Delphi	Construction	No
[5]	Control (Safety)	Survey	Manufacturing	No
[6]	Cobot evolution	Review	General	No
[7]	Competencies	Delphi	Construction	No
[8]	Trust/Safety	Experimental	Manufacturing	Yes
[9]	Workspace safety	Tech. review	Manufacturing	No
[10]	Org. human factors	Exploratory	General	No
[11]	Collision avoidance	Multi-disc. rev.	Manufacturing	No
[12]	Lab-to-industry	Project review	Manufacturing	No
[13]	Org. human factors	Exploratory	General	No
[14]	Competencies	Delphi	Construction	No
[15]	Control (all 3)	Survey	Manufacturing	No

Table III
Comparison Of Key Hrc Perception Modules

Module	Method	Dataset	FPS	Acc.(%)
Human Skeleton	Lightweight OpenPose	COCO 2017	30	91
Action Recog.	ST-GCN	NTU RGB+D	20–30	87
Object Detection	Mask R-CNN	Custom (280K)	2.6–6	93
3D Pose	VoxelPose	Campus, Shelf	10–15	~90
Gesture Recog.	CNN + Depth	ASL/Custom	25+	85–95

F1 — Perception is deployable but not yet production-ready. Deep learning models for skeleton detection, gesture recognition, and object detection have achieved sufficient accuracy and speed for many industrial tasks. However, gen- eralization to new environments, robustness to industrial noise and occlusion, and quantifiable reliability under safety-critical conditions remain unresolved [1]. Custom data collection for each new product or environment is resource-intensive, requiring 2–3 days per 200 annotated images.

F2 — Safety is necessary but insufficient alone. Safety is the most extensively studied HRC target, driven by regula- tory requirements (ISO/TS 15066). Control Barrier Functions (CBFs) and NMPC represent the state of the art in mathemat- ically rigorous safety guarantees. However, focusing exclu- sively on safety at the expense of ergonomics and efficiency produces systems that are safe but operationally suboptimal [5], [15]. Only 12% of surveyed papers address dual targets, and none simultaneously optimize all three.

F3 — Ergonomics demands greater attention. Phys- ical ergonomics reduces MSDs through task allocation and biologically-inspired trajectory planning. Cognitive ergonomics—addressing worker stress, trust, and psychologi- cal safety near robots—is substantially less developed. Studies by Maurtua et al. [8] and Charalambous et al. [10] demonstrate that worker trust and acceptance are not automatic and require deliberate design of interaction modalities and organizational support structures.

F4 — Industry 5.0 reframes the HRC goal. The evo- lution from Industry 4.0 to Industry 5.0 shifts the primary objective of HRC from efficiency maximization to human- centric collaboration [2], [6]. This requires HRC systems to be proactive—anticipating human needs rather than merely react- ing to them—and requires the integration of human well-being metrics into optimization objectives alongside throughput and cycle time.

F5 — Workforce competencies are a critical deploy- ment factor. Technical excellence alone does not guarantee successful HRC deployment. The Delphi studies by Olukanni et al. [4], [7], [14] demonstrate that knowledge of human-robot interfaces, safety standards, and task planning are the most critical competencies for HRC workers. The persistent gap between industry and academia in competency prioritization means that graduates entering the workforce may lack the operational skills most valued by employers.

F6 — Organizational factors are systematically over- looked. Charalambous et al. [10], [13] identify that the absence of formal frameworks for managing organizational change, building worker trust, and restructuring job roles around HRC is a systemic gap in the field. Engineering research tends to treat the human as a static element in the HRC system when in reality the human is a dynamic participant whose behavior, attitude, and capabilities evolve with experience.

B. Remaining Open Challenges

Based on the comparative analysis, the following challenges remain open and represent high-priority directions for future research:

- Integrated multi-target control frameworks that simulta- neously optimize safety, ergonomics, and efficiency with real-time computational feasibility.
- Standardized benchmarks for evaluating HRC system performance across safety, ergonomic, and efficiency dimensions in real industrial environments.
- Generalizable perception models that can adapt to new environments, products, and operators without requiring extensive custom data collection.
- Formal organizational frameworks for HRC deployment that address change management, trust-building, and workforce transition.
- Industry-aligned educational curricula that bridge the gap between academic theory and operational HRC compe- tencies.

VII. CONCLUSION

This paper has presented a comprehensive survey of Human-Robot Collaboration in industrial environments, cover- ing fifteen key studies across sensor-based perception, control techniques, workforce competencies, organizational factors, and industrial applications. The survey is structured across a full literature review table, thematic discussion, methodology classification, comparative analysis, and synthesis of results.

The principal conclusion is that HRC research has matured significantly in its technical dimensions—particularly safety-oriented control and deep learning-based perception— but remains fragmented. The three core objectives of safety, ergonomics, and efficiency are rarely addressed jointly. Or- ganizational human factors, workforce competencies, and the lab-to-industry transition receive comparatively less attention despite being critical determinants of real-world deployment success.

Looking ahead, Industry 5.0 provides a compelling norma- tive framework for redirecting HRC research toward human- centric objectives: sustainability, resilience, worker well-being, and ethical human-robot authority sharing. Realizing this vision requires not only technical innovation but interdisci- plinary collaboration spanning robotics, control engineering, ergonomics, organizational psychology, and vocational educa- tion. The authors anticipate that addressing the identified gaps will unlock the full transformative potential of HRC across manufacturing, construction, healthcare, and beyond.

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REFERENCES

1. A. Angleraud et al., “Sensor-based human-robot collaboration for indus- trial tasks,” Robot. Comput.-Integr. Manuf., 2024.
2. A. Baratta et al., “Human robot collaboration in industry 4.0: A literature review,” Procedia Comput. Sci., 2023.
3. U. Othman and E. Yang, “An overview of human-robot collaboration in smart manufacturing,” in Proc. 27th Int. Conf. Autom. Comput. (ICAC), 2022.
4. E. Olukanni et al., “Competencies for human-robot collaboration in the construction industry: Perspectives from academia and industry,” Constr. Robot., 2025.
5. S. Proia, R. Carli, G. Cavone, and M. Dotoli, “Control techniques for safe, ergonomic, and efficient human-robot collaboration in the digital industry: A survey,” IEEE Trans. Autom. Sci. Eng., vol. 19, no. 3, pp. 1798–1819, Jul. 2022.
6. Raffik R. et al., “Industry 5.0: Enhancing human-robot collaboration through collaborative robots—A review,” in Proc. 2nd Int. Conf. Ad- vancements Electr., Electron., Commun., Comput. Autom. (ICAECA), 2023.
7. E. Olukanni et al., “Industry perception of competencies for human-robot collaboration in construction: A Delphi study,” Front. Eng. Manag., 2025.
8. I. Maurtua, A. Ibarguren, J. Kildal, L. Susperregi, and B. Sierra, “Human-robot collaboration in industrial applications: Safety, interaction and trust,” Int. J. Adv. Robot. Syst., 2017.
9. A. Vysocky and P. Novak, “Human-robot collaboration in industry,” MM Sci. J., 2016.
10. G. Charalambous, S. Fletcher, and P. Webb, “Identifying the key organisational human factors for introducing human-robot collaboration in industry: An exploratory study,” Int. J. Adv. Manuf. Technol., 2015.
11. S. Robla-Go´mez et al., “Working together: A review on safe human- robot collaboration in industrial environments,” IEEE Access, 2017.
12. Z. Doulgeri and F. Dimeas, Eds., Human-Robot Collaboration: Unlock- ing the Potential for Industrial Applications. IET Control, Robotics and Sensors Series, 2026.
13. G. Charalambous, S. Fletcher, and P. Webb, “Identifying the key organisational human factors

for introducing human-robot collaboration in industry: An exploratory study," Int. J. Adv. Manuf. Technol., 2015.

14. E. Olukanni et al., "Industry perception of competencies for human- robot collaboration in the construction industry: A Delphi study," Front. Eng. Manag., 2025.
15. S. Proia, R. Carli, G. Cavone, and M. Dotoli, "Control techniques for safe, ergonomic, and efficient human-robot collaboration in the digital industry: A survey," IEEE Trans. Autom. Sci. Eng., vol. 19, no. 3, pp. 1798–1819, Jul. 2022.