Barriers and challenges for AI and HRC integration

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Abstract

The flexibility provided by collaborative robotics is making it increasingly relevant in industrial scenarios. However, this growth is also highlighting the existing limitations and integration challenges of both collaborative robotics and the AI that supports many of its applications. This paper outlines the main challenges identified that hinder the integration of Human-Robot Collaboration at different levels of interaction: physical contact management, object handling, environment avoidance, task scheduling and management and task scheduling adaptation. These challenges have been focused and analyzed from the perspective of the specific use cases of the AI-PRISM project.

Keywords

HRC, Challenges, AI-PRISM, Artificial Intelligence

1. Introduction

Modern industry, with its trend towards smaller and more customized production batches, necessitates increased flexibility and adaptability [1; 2]. Traditional industry struggles to adapt to unforeseen situations or production changes [3], while full automation remains costly and complex [4]. The combination of robots for precision and repeatability with human workers for flexibility in shared tasks offers a cost-effective solution [5; 6], often utilizing collaborative robots (cobots) to ensure operator safety [7; 8].

However, ensuring human safety in enclosure-free shared workspaces requires effective human-robot interaction (HRI) techniques [7; 8]. HRI techniques aim to facilitate safe interactions between robots and human workers in collaborative scenarios. These interactions are categorized into four levels based on the degree of human-robot interaction [9]:

- Task design level: It corresponds to safety and the human-robot interaction itself during the execution of tasks in different degrees of automation.
- Operation level: Focuses on the actions executed by the robot and aspects related to its environment such as obstacle avoidance and smooth workflow between human and robots.
- Work cell level: Focuses on the coordination of tasks to optimize sub-processes and reduce risk situations by optimal planning of tasks and sub-processes.
- Process level: finally, the management of sub-processes to ensure the production objectives are performed at the process level.

Addressing various aspects of human-robot interaction within collaborative applications presents challenges crucial for ensuring safety, efficiency, and productivity. These challenges include managing physical contact, handling objects, navigating environments, and task scheduling and adaptation [9].

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Effective management of **physical contact** is essential for ensuring the safety of human operators in shared environments, encompassing both expected interactions (e.g., teaching or hand-guiding applications) and unexpected collisions. Effective management of **physical contact** is essential for ensuring the safety of human operators in shared environments, encompassing both expected interactions (e.g., teaching or hand-guiding applications) and unexpected collisions. .

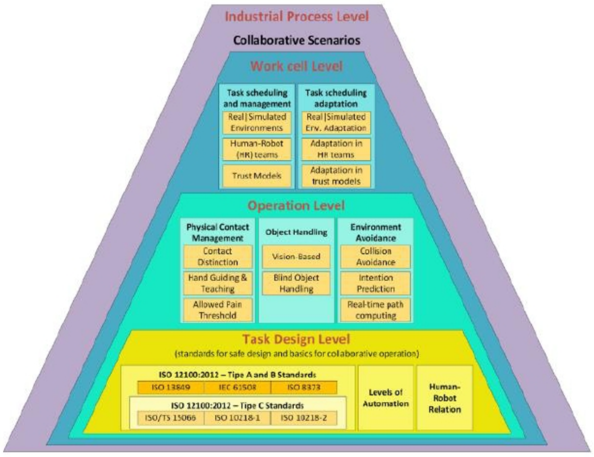

Figure 1: Automation and integration levels and challenges [9].

Improper **object handling** poses risks to human workers, necessitating the ability to handle objects in the workspace, especially deformable or complex items. Avoiding contact entirely is sometimes necessary for process efficiency or safety, highlighting the critical need for evasion capabilities when **navigating** in shared environments to prevent safety stops or blockages.

Finally, at the work-cell level, **task scheduling, management, and adaptation** are pivotal for collaborative processes. Optimizing task scheduling in shared environments is crucial for productivity and operator safety, minimizing potential risks and collisions. Additionally, adapting production and planning to unforeseen changes is vital for maintaining process quality amidst disruptions, such as process or machine failures.

Next, the paper proceeds to present AI-PRISM project use cases, focusing the identified challenges and solutions into the selected industrial use cases.

2. Main Challenges and Barriers in Use cases

This section delves into the main challenges and barriers confronted by the current industrial framework that would encourage the deployment of human-robot collaborative solutions. These industrial barriers are tackled by the AI-PRISM project, which represents a comprehensive research initiative with the goal of providing adaptable AI-based solutions for the manufacturing industry. The project addresses challenges in unpredictable manufacturing scenarios, emphasizing flexible and collaborative environments with human-robot interaction and integrates human-centered AI concepts with the objective to overcome adoption barriers. Said solution encompasses a robotic platform designed to streamline the automation of challenging tasks, creating a human-robot cooperative environment. This includes an AI-monitored robot human relationship to prevent unsafe situations and the necessary infrastructure for seamless integration.

Five use cases within AI-PRISM, have been selected for the integration of collaborative scenarios addressing the physical and psychological fatigue of the operator. In furniture manufacturing, automation faces challenges due to the complexity and quality standards of tasks such as preparation, painting, and finishing wooden parts. The electronics use case focuses on precise automatic positioning of components to reduce human stress. In food and beverages, scenarios include handling hazardous materials, sorting bottles, applying stickers, managing broken glass, and packaging custom orders. Product assembly entails testing appliances and final packaging. Discrete manufacturing involves visualizing and recognizing PCBs, testing them, and transporting them. These use cases emphasize the existing diversity of challenges (see Table 1) across the industrial framework to deploy safe human-robot collaborative solutions.

Table 1.
Mapping of Main Challenges and Barriers in AI-PRISM Pilot use cases.

Challenges	Furniture	Electronics	Food & Beverages	Consumer Electronics Assembly	Discrete Manufacture
Work Cell Level	X	X	X	X	X
Task scheduling and management	X		X		X
Task scheduling adaptation	X	X	X	X	X
Operation Level	**X**	**X**	**X**	**X**	**X**
Physical contact management	X				
Object handling		X	X	X	X
Environment Avoidance			X		X
Task Design Level	**X**	**X**	**X**	**X**	**X**
Safety	X		X	X	
Human Robot Collaboration	X	X	X	X	X

Following, each use case is thoroughly elucidated, providing a process overview and a step by-step breakdown. Additionally, the narrative details the roles of both the robotic assistant and the human operator, emphasizing their collaboration in addressing their specific challenges.

2.1. Furniture Use Case

This case studies the painting process of a factory of small furniture. Our goal is to enhance its painting process to cope with increased production demands. Figure 2 shows operations involved in painting process.

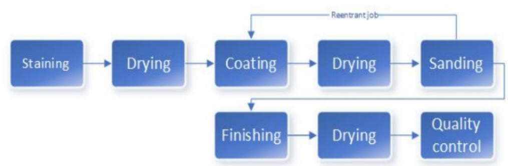

Figure 2: Painting process with stages and reentrant jobs.

The first challenge lies in the reliance on skilled workers for painting tasks by integrating collaborative robots (cobots). These robots will share duties with skilled workers, allowing the latter to move to other tasks if needed.

To enhance production efficiency, an AI-based application will be developed to optimize task scheduling and scheduling adaptation at work cell level. This application will oversee the plant resource management, including human workers, robot training planification and schedule adaptation when unforeseen events occur.

A cobot will be introduced in the paining cell in charge of the finishing operation. This cobot will be trained in a training cell, by a skilled worker. Once the cobot is trained it can replace the painter when needed or assist this same worker in painting tasks. The cobot will provide security measures to avoid contact with the worker. In case the worker gets close to the collaborative robot it will reduce velocity and stop before contact.

The introduction of collaborative robots requires adjustments in production planning and scheduling. This includes accommodating new tasks, training robots for new products, and integrating robot training into production planning.

To address these challenges, a standardized data model based on the ISA95 standard will facilitate clearer communication of information among different services, data sources, and third party software. Data transformation and validation services will ensure seamless integration with the standardized model, promoting interoperability across different environments.

2.2. Electronics Use Case

This case studies the precise positioning process of chips at VIGO Photonics, a European manufacturer of semiconducting materials and instruments for photonic and microelectronic, specialized in LWIR and MWIR detectors and modules. The manufacturing process is largely based on manual activities and the operator's experience. So far, the most challenging and time consuming moment is finding the center of the chip - specifically, the center of the physical structure of the semiconductor layers. The process currently is done manually by the operator by turning knobs on a mechanical XY stage and the following problems were identified: high degree of production rejects, long procedure time, and long-term concentration by the operator [10]. A robotic arm is replaced by a precise XY stage and a microscope camera. The use of such a set is necessary due to the size of semiconductor structures, which usually have dimensions of micrometers.

For this process, several stages take place: station calibration, inserting the chip, finding the structure center, and stick (wire) insertion and gluing.

Due to short production runs and not always having precisely defined features, AI will be used to find the center of the chip. The positioning of the motorized table is performed automatically by a driver equipped with AI-based algorithm. Additionally, it will be possible to detect manufacturing defects in semiconductors.

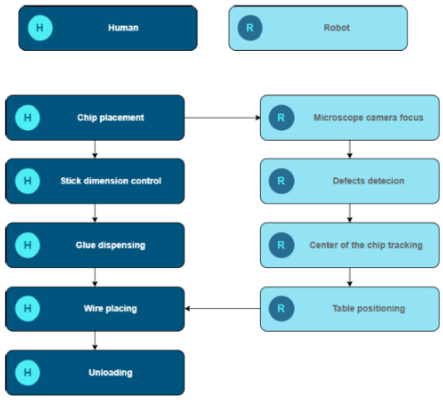

Figure 3: Use case stages.

In this case, human robot collaboration is unique because it is on a micro scale. This involves relieving the operator of the most stressful and time-consuming tasks, especially since full automation of the cycle in this scenario has no economic or practical justification..

2.3. Food and Beverages Use Case

In the Food and Beverages sector, three use cases are considered in Athenian Brewery premises.

Filtration Preparation Process: This process involves heavy tasks and handling hazardous chemical compounds delivered in powder form. To enhance **safety** and **human-robot collaboration**, a collaborative robot (cobot) is integrated into the operational area. The cobot assists in transporting sacks onto the conveyor belt while the human operator monitors the environment and intervenes when necessary. This integration optimizes task allocation, ensuring efficient and safe filtration preparation.


Figure 4: Heavy lifting process

Return Bottle Sorting: The brewery implements a large automation system to sort return bottles from the market. A robotic manipulator depalletizes crates, and trained personnel categorize the bottles based on their type. Safety considerations are paramount due to the delicate nature of glass bottles. To ease the workload of human workers and enhance sorting accuracy, a cobot equipped with a machine vision system is introduced. This cobot aids in the bottle sorting process, contributing to a more organized and efficient operation.

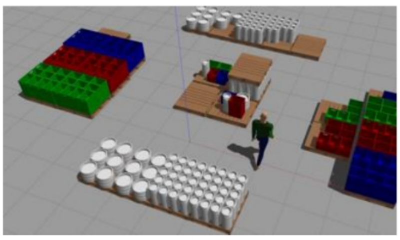
Figure 5: Heavy lifting process

2.4. Consumer Electronics Assembly Use Case

The Silverline use case involves demonstrating the integration of the Robot Operating System (ROS) into industrial settings, focusing on safety, efficiency, and optimization. This integration is analyzed across four levels of HRI: Task Design, Operation, Work Cell, and Process.


Figure 6: Visual testing

At the Task Design Level, we aimed to ensure safe collaboration between robots and humans, considering safety protocols and interaction mechanisms for efficient task execution. This involved orchestrating robot actions, including navigation and workflow integration with human workers, to ensure effectiveness. At the Work Cell Level, optimization of task coordination was prioritized, involving planning and scheduling to enhance subprocess efficiency. Furthermore, at the Process Level, effective management of subprocesses was implemented to align with production objectives, ensuring coordination between robotic and human activities for maximum productivity.

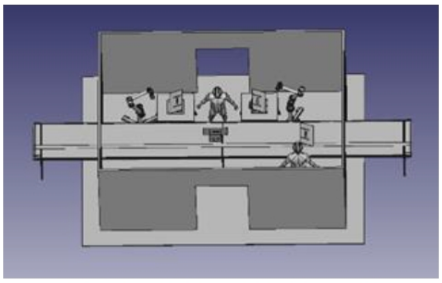

Figure 7: Working Cell layout

Overall, the integration addresses safety, efficiency, and optimization, providing valuable insights into ROS integration's practical aspects. These insights contribute to the broader field of HRI in industrial applications.

The challenges encountered and solutions devised in this project highlight the importance of ROS integration for enhancing industrial processes and ensuring collaboration between humans and robots. This approach underscores the significance of ROS in driving productivity and goal attainment in industrial environments, ultimately contributing to advancements in HRI.

2.5. Discrete Manufacturing Use Case

The use case targets the integration of collaborative robots to aid in the production and testing of Printed Circuit Boards (PCBs), aiming to address challenges associated with manual handling and testing tasks. Human operators currently perform these tasks, which involve loading PCBs into testing fixtures and configuring work cells for different PCB types, leading to issues like repetitive tasks and potential mental fatigue. AI-PRISM proposes introducing collaborative robots into the process to alleviate these challenges.

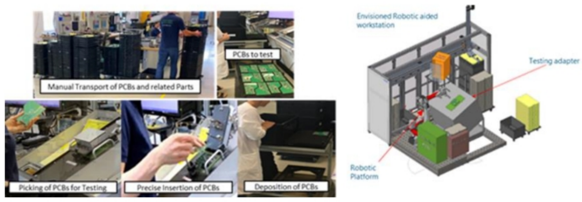

Figure 8: (Left) Shows the manual PCB handling process at KEBA which produces 200 different types of PCBs; (Right) depicts the envisioned robotic-aided work cell for handling and testing the different PCBs.

Two scenarios are envisioned for **human-robot collaboration**: the first involves a static robotic manipulator handling and testing PCBs, aiming to reduce strain on human operators and ensure consistent and precise testing. The second focuses on configuring work cells for new PCB types, where a mobile robot assists humans by carrying necessary parts and facilitating assembly. Additionally, easy-to-use interfaces enable non-expert users to configure robotic tasks quickly.

Challenges and barriers are categorized into four levels of interaction: task design, operation, work cell, and process. These include minimizing strain on operators, optimizing robot actions and navigation, coordinating tasks within work cells, and managing sub-processes to meet production objectives. Overcoming these challenges is crucial for the successful integration of collaborative robots into the PCB production and testing process, improving efficiency and reducing human strain.

3. Conclusions

The integration of artificial intelligence (AI) and human-robot collaboration (HRC) introduces a spectrum of challenges and barriers that demand careful consideration. Throughout the exploration of the challenges embedded in these use cases we can highlight the difference in nature that exists between said challenges, ranging between very different industrial scenarios and tasks, empathizing the necessity of successfully integrating of human-robot collaborative solutions, ensuring not only the safety and efficiency of operations but also the required adaptability for unpredictable manufacturing scenarios. This adaptability would be implemented by a user-friendly approach which would allow individuals without expertise in robotics to effectively 'program' robots for complex and demanding tasks. Stated so, AI-PRISM would help to address and overcome the barriers and challenges due to the simplicity practicality of the solution.

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Declaration on Generative AI

The author(s) have not employed any Generative AI tools.

References

[1] A. Hentout, A. Mustapha, A. Maoudj, and I. Akli, "Key challenges and open issues of industrial collaborative robotics," in Proc. Workshop Hum.-Robot Interact., From Service Ind. (RO-MAN), Aug. 2018, pp. 1_4.

[2] K. Karlsson and M. Jonsson, "Overview of SAAB in commercial aeronautics. Clean Sky 2 and ITD AIRFRAME research and SAAB aerostructures automation projects and strategy," in Proc. Oportunidades de la Robótica Para Empresas Del Sector Aeronáutico, Eibar, Spain, 2019

[3] J. M. Beer, A. D. Fisk, and W. A. Rogers, "Toward a framework for levels of robot autonomy in human-robot interaction," J. Hum.-Robot Interact., vol. 3, no. 2, p. 74, Jun. 2014.

[4] F. Barravecchia, L. Mastrogiacomo, and F. Franceschini. "A general cost model to assess the implementation of collaborative robots in assembly processes". in Int J Adv Manuf Technol 125, pp. 5247–5266, 2023.

[5] L. Gualtieri, I. Palomba, E. J. Wehrle, and R. Vidoni, "The opportunities and challenges of SME manufacturing automation: Safety and ergonomics in human-robot collaboration," in Industry 4.0 for SMEs: Challenges, Opportunities and Requirements, D. T. Matt, V. Modrák, and H. Zsifkovits, Eds. New York, NY, USA: Macmillan, 2020, ch. 4, pp. 105-144.

[6] Quality Inspection Org. (2017). Benefits of Semi-Automation. [Online]. Available: https://qualityinspection.org/semi-automation/

[7] Universal Robots. (2018). Cuáles Son Las Diferencias Entre Un Cobot y Un Robot Industrial? [Online]. Available: https://blog.universalrobots.com/es/cobots-vs-robots industriales.

[8] F. Vicentini, M. Askarpour, M. G. Rossi, and D. Mandrioli, "Safety assessment of collaborative robotics through automated formal verication," IEEE Trans. Robot., vol. 36, no. 1, pp. 4261, Feb. 2020.

[9] D. Rodríguez-Guerra, G. Sorrosal, I. Cabanes and C. Calleja, "Human-Robot Interaction Review: Challenges and Solutions for Modern Industrial Environments," in IEEE Access, vol. 9, pp. 108557-108578, 2021.

[10] Eimontaite, Iveta & Fletcher, Sarah & Goławski, Krystian & Kołcon, Tomasz. (2023). Breaking the barriers: multilingual user engagement to increase process engagement and technology acceptance in manufacturing. 10.54941/ahfe1003503.