Robots learn to behave: improving human-robot collaboration in flexible manufacturing applications

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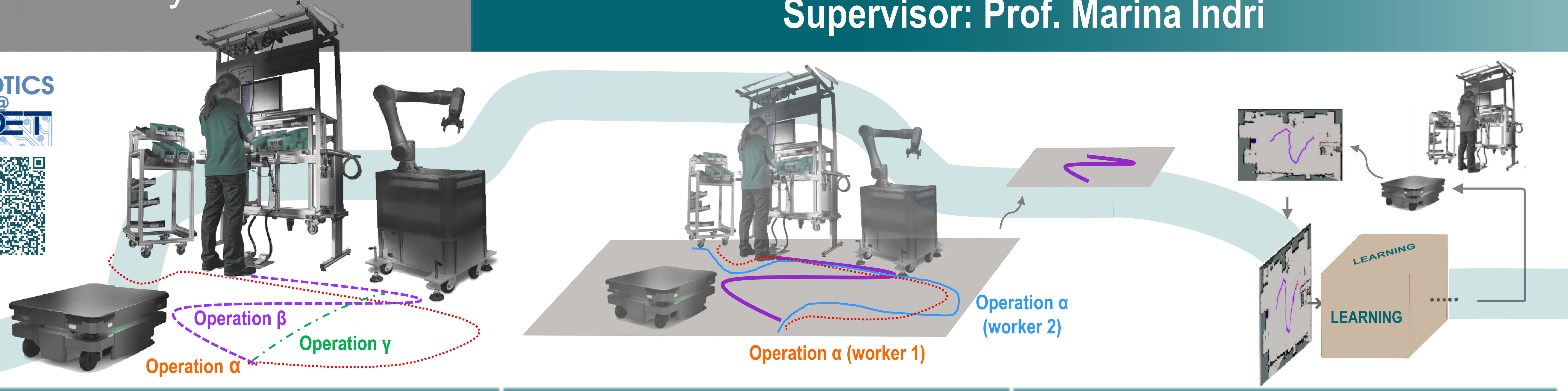
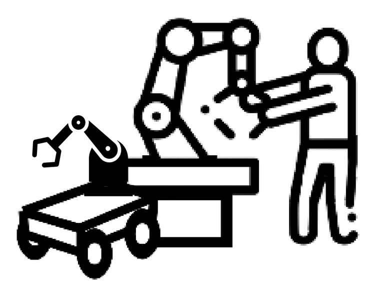


Learning to recognize manufacturing operations can improve the behaviour of robots during collaborative interactions | Collecting data – e.g., path plots – which is independent of the human body features can improve generalization and removes bias | Data whose relevant features are captured by images can be processed exploiting well-established, image-based learning algorithms

Research context and motivation

Over the past decades, industrial revolutions hinted to future fully automated scenarios, where humans would have taken on the role of mere supervisors. However, the need for mass product customization, rather than mass production, has led to a new concept of production line, where robots share workspaces with humans [1]. The solutions envisaged by Industry 5.0 are human-centered and flexible manufacturing setups, where fixed-base and mobile robots collaborate with humans. This interaction has yet to become smooth given the difference in cognitive capabilities [7]. To teach robots the correct and safe behaviour during collaboration, artificial intelligence can be leveraged to enable operation recognition and allow for learning.



Addressed research questions/problems

- How can we teach robots how to behave? How to overcome the cognitive mismatch to improve collaboration interactions?
- Is there a tradeoff between complex/data-hungry solutions and sustainable but feasible minimal ones, exploiting unbiased data?

Novel contributions

- The integration of open source tools, libraries and data, led to the development of a framework that exploits well-established state-of-the-art algorithms to tackle the challenge of improving collaborative manufacturing tasks.
- The developed operation recognition feature demonstrates that minimal but useful results can be achieved even in case of data scarcity, exploiting data that is independent of the body features of the operator.
- The robot learns by training on human operations demonstrations, to move accordingly given a-priori information on the associated desired behaviour.

This research main bring away is the following: knowledge sharing, cross-field contamination and tool integration are key to foster innovation.

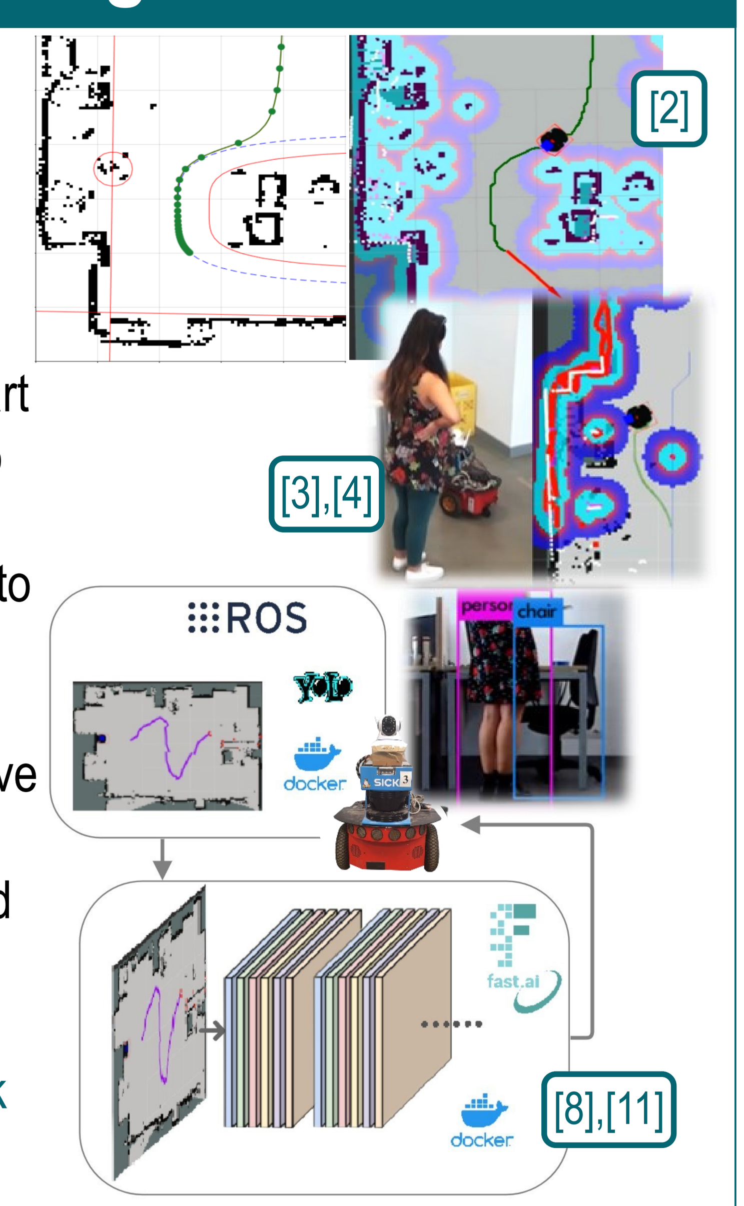
Adopted methodologies

To implement an autonomous mobile robot, a wheeled mobile demonstrator has been made capable of:

- following a supervised safe path generated exploiting attractive curves and barrier functions, using a modified version of the A* global planner [2]
- detecting human obstacles, through a state-of-the-art neural network-based object detection algorithm, so as to overcome them conservatively [3]
- triggering the online re-computation of global plans to follow the safe curve when a human is detected [4]

To implement the learning capabilities in order to improve collaboration, the demonstrator:

- monitors the scene where the human is working and collects data on the operator's 2D motion as map images [5],[8]
- uses map images for training a deep neural network to learn how to recognize performed operations [11]



Submitted and published works

1. Indri, M., Lachello, L., Lazzero, I., Sibona, F., and Trapani, S., "Smart sensors applications for a new paradigm of a production line", Sensors, 19(3), 2019, 650.
2. Indri, M., Possieri, C., Sibona, F., Cheng, P. D. C., and Hoang, V. D., "Supervised global path planning for mobile robots with obstacle avoidance", 24th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA), Zaragoza, 2019, pp. 601-608.
3. Indri, M., Sibona, F., and Cen Cheng, P. D., "Sensor data fusion for smart AMRs in human-shared industrial workspaces", 45th Annual Conference of the IEEE Industrial Electronics Society (IECON), Lisbona, 2019, Vol. 1, pp. 738-743.
4. Indri, M., Sibona, F., Cen Cheng, P. D., and Possieri, C., "Online supervised global path planning for AMRs with human-obstacle avoidance", 25th IEEE international conference on emerging technologies and factory automation (ETFA), Vienna [online], 2020, Vol. 1, pp. 1473-1479.
5. Indri, M., Sibona, F., and Cen Cheng, P. D., "Sen3Bot Net: A meta-sensors network to enable smart factories implementation", 25th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA), Vienna [online], 2020, Vol. 1, pp. 719-726.
6. Sibona, F., Cen Cheng, P. D., Indri, M., and Di Prima, D., "PoinTap system: a human-robot interface to enable remotely controlled tasks", 26th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA), Västerås [online], 2021, pp. 01-08.
7. Bonci, A., Cen Cheng, P. D., Indri, M., Nabissi, G., and Sibona, F., "Human-robot perception in industrial environments: A survey", Sensors, 21(5), 1571.
8. Sibona, F., and Indri, M., "Data-driven framework to improve collaborative human-robot flexible manufacturing applications", 47th Annual Conference of the IEEE Industrial Electronics Society (IECON), Toronto [online], 2021, pp. 1-6.
9. Cen Cheng, P. D., Indri, M., Sibona, F., De Rose, M., Prato, G., "Dynamic Path Planning of a mobile robot adopting a costmap layer approach in ROS2", 27th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA),Stuttgart, 2022, [*presented in September - in press*].
10. Cen Cheng, P. D., Sibona, F., Indri, M., "A framework for safe and intuitive human-robot interaction for assistant robotics", 27th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA),Stuttgart, 2022, [*presented in September - in press*].
11. Sibona, F., Cen Cheng, P. D., Indri, M., "How to improve human-robot collaborative applications through operation recognition based on human 2D motion", 48th Annual Conference of the Industrial Electronics Society (IECON), Bruxelles, 2022, [*to be presented in October - in press*].
12. Cen Cheng, P. D., Indri, M., Possieri, C., Sassano M., Sibona, F., "Path planning in formation and collision avoidance for multi-agent systems", Nonlinear analysis: Hybrid systems (2022) [*accepted, in press*].

Future work

The current research, brought on as a visiting PhD at the R2C lab - TU Delft (NL), is focused on the use of machine learning algorithms, such as reinforcement learning and gaussian processes, to implement *interactive learning* with fixed-base collaborative manipulators. This will allow to enrich the scope of investigation of the project.

List of attended classes

Hard Skills Courses (Politecnico di Torino)

- 01UMNRV – Advanced deep Learning (didattica di eccellenza) (15/6/2021, 40 pts)
- 01UJBRV – Adversarial training of neural networks (2/7/2020, 25.00 pts)
- 01UJTIU – Control and data acquisition automation in scientific experiments (25/6/2020, 13.33 pts)
- 01LCPRV – Experimental modeling: costruzione di modelli da dati sperimentali (30/7/2020, 44.00)
- 01QSAIU – Heuristics and metaheuristics for problem solving: new trends and software tools (10/7/2020, 26.67 pts)
- 01UMEKG – Principles of deep learning (18/9/2020, 33.33 pts)
- 01SFURV – Programmazione scientifica avanzata in matlab (29/6/2020, 37.33 pts)

Others: Model Predictive Contro(01/04/2022, 20 pts) [online-Scuola IMT Alti Studi Lucca] - Game Theory and Network Systems | Modeling and Control of Soft Robots (12/07/2021, 30 pts) [S.I.D.R.A. PhD Summer School]

Soft Skills Courses

- 02LWHRV – Communication (3/12/2019, 6.67 pts)
- 01UNRRV – Entrepreneurship and start-up creation (3/7/2020, 66.67)
- 01RISRV – Public speaking (29/12/2019, 6.67 pts)
- 01SWPRV – Time management (7/11/2019, 2.67 pts)
- 01QORRV – Writing Scientific Papers in English (20/2/2020, 20.00 pts)

Awards and programs

- Innovation 4 Change 2020 program participant (Collège des Ingénieurs Italia, Politecnico di Torino & CERN Ideasquare)
- ETH Robotics Summer School 2021 participant (ETH Zürich)
- EECE PhD Quality Award 2022 winner (Politecnico di Torino)
- IES-SYPA 3M Video contest 2022 winner (IEEE Industrial Electronics Society - Student & Young Professionals)

Politecnico di Torino 1859

PhD program in
Electrical, Electronics and Communications Engineering