Perception and motion control algorithms for proactive safety in collaborative automation.

Ph.D. candidate

Federico Parma

Cycle

XL

Tutors

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1. Description of the research program

The research activity focuses on online replanning strategies in collaborative robotics, with an initial goal of achieving proactive safety within the robotic cell by integrating a Human Intent Estimation Model with an online replanning algorithm. In Human-Robot Interaction (HRI), designing algorithms that can predict operator movements and adapt manipulator trajectories in real-time is essential to enhance efficiency and safety. This is particularly relevant in today's industrial and social contexts, where, in recent years, there has been a significant increase in robots sharing workspace with human operators.

Significant challenges must be addressed to make this an actual solution. First, implementing the replanning algorithm: recalculating trajectories from scratch whenever an obstacle obstructs the current path is often inefficient and time-consuming. Thus, the chosen solution must prioritize responsiveness and efficiency in generating viable solutions. Another challenge is selecting an appropriate Intent Estimation Model. All predictive models are subject to inherent uncertainties; human behavior can be unpredictable, and planning based solely on expected movements can lead to unsafe trajectories. Consequently, providing confidence intervals of these predictions is crucial, enabling the replanner to make informed decisions and adjust its strategies accordingly.

By incorporating safety sensors manufactured by Inxpect, this research also seeks to implement dynamic safety zones within the robotic cell, allowing for the precise delineation of areas where the robot can operate at higher speeds, thereby enhancing operational efficiency.

A potential advancement of these research themes includes developing proactive safety within a controlled automation scenario: in the working environment, all automation devices would be interconnected, sharing safety information, such as the operators' position, to swiftly adapt their behavior even in situations where a particular device may be obstructed.

The PhD thesis will be developed in the Joint Research Lab (JRL) "Laboratorio di Controlli Automatici per la Robotica Intelligente", born from the collaboration between Università degli Studi di Brescia and CNR-STIIMA.

The simulations will be conducted using ROS2-based environments like Gazebo or Pybullet. The final testing on real hardware will still be based on ROS2. Specifically, it will be conducted on a UR10-ESeries, a collaborative robot from Universal Robotics. The one available at the JRL is ceiling-mounted on a horizontal slide bar, allowing for additional freedom.

Figure 1 Robotic Cell in JRL-CARI

2. Schedule of the research activities

Note: the period spent within the company fill be from 01/03/2026 to 31/09/2026

First academic year (planned)

	Description	Period	Activity abroad
Bibliographic research	Keeping up with the state of the art about online replanning literature to define the most suitable algortithm to be implemented during the project.	11/2024-01/2025	NO
First algorithm development	Implementation of the first online replanning algorithm.	02/2025–05/2025	NO
Studying of Inxpect sensors	Study of the sensors provided by Inxpect, with the aim of selecting the most appropriate product.	06/2025–07/2025	NO
Test phase	Initial phase of simulation and testing of the previously developed algorithm, incorporating Inxpect products into the experimental setup for motion detection and operator position estimation.	08/2025-10/2025	NO

Second academic year (planned)

	Description	Period	Activity abroad
Studying of Intent Estimation Models	Research and investigation of the most suitable human model for the project.	11/2025-02/2026	NO
Integration with the online path replanning	Development of an "Intent Estimation Module" to be integrated with the replanning algorithm, to ensure proactive safety in the human robot collaboration context. **Period spent within the company**	03/2026-06/2026	NO
Validation of the model and the algorithm	Validation of the model and second phase of simulation and test. **Period spent within the company.**	07/2026-09/2026	NO

Third academic year (planned)

	Description	Period	Activity abroad
Abroad project	TBD	10/2026–03/2027	YES
Refinement of the algorithm	Refinement of the algorithm, followed by more in depth tests.	04/2027-08/2027	NO
Thesis writing		09/2027-10/2027	NO

3. Training and research activities plan

First academic year (planned)

		Description	Period	Final Exam	ECTS
A.	**Ph.D. courses**	Intelligent Supervision Systems	01/2025-02/2025	Yes	2
		Human Autonomous System Interaction	02/2025-03/2025	Yes	1
		Game Theory for Controlling Autonomous Systems	06/2025	Yes	1
		Optimal Control for Climate Change and Air Quality	06/2025	Yes	2
		Scrittura scientifica (DRIMI -Unibs)	01/2025	Yes	2
		Control of solar energy systems (DRIMI -Unibs)	05/2025	Yes	1
		PID Control: Review of methods and new approaches (DRIMI -Unibs)	06/2025	Yes	1
		Path e Motion planning nei sistemi di controllo meccatronici (DRIMI -Unibs)	09/2025	Yes	1
		Neural Networks and Deep Learning: Theoretical Foundations (DRIM)	01/2025	Yes	2
		Automated Planning (DRIM)	07/2025	Yes	1
B.	**Master's degree courses**	Scuola di dottorato SIDRA		No	5
C.	**Soft skill courses**				
D.	**Participation to seminars**				
E.	**Participation to international congresses or workshops**	ETFA - IEEE International Conference on Emerging Technologies and Factory Automation			4
F.	**Presentation of research products at international congresses or workshops**	ETFA - IEEE International Conference on Emerging Technologies and Factory Automation			2
		TOTAL OF ECTS FOR TRAINING ACTIVITIES			25
G.	**Individual research activity**				25
H.	**Supervision of students**				4
I.	**Integrative teaching activities**				1
J.	**Preparation of manuscripts for conferences or journals**				5
		TOTAL OF ECTS FOR RESEARCH ACTIVITIES			35
		TOTAL OF ECTS			**60**

Second academic year (planned)

	Description	Period	Final Exam	ECTS
A. Ph.D. courses				
B. Master's degree courses				
C. Soft skill courses				
D. Participation to seminars				
E. Participation to international congresses or workshops				
F. Presentation of research products at international congresses or workshops				
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			15
G. Individual research activity				35
H. Supervision of students				4
I. Integrative teaching activities				1
J. Preparation of manuscripts for conferences or journals				5
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			45
	TOTAL OF ECTS			**60**

Third academic year (planned)

	Description	Period	Final Exam	ECTS
A. Ph.D. courses				
B. Master's degree courses				
C. Soft skill courses				
D. Participation to seminars				
E. Participation to international congresses or workshops				
F. Presentation of research products at international congresses or workshops				
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			5
G. Individual research activity				45

H.	**Supervision of students**				4
I.	**Integrative teaching activities**				1
J.	**Preparation of manuscripts for conferences or journals**				5
		TOTAL OF ECTS FOR RESEARCH ACTIVITIES			55
		TOTAL OF ECTS			**60**

4. List of the publications written by the candidate in the triennium