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DEPARTMENT OF INFORMATION ENGINEERING
UNIVERSITY OF PADOVA

Integrating Task and Motion Planning Techniques for Security and Efficiency of Robotized Manufacturing Processes

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La Robotica Industriale protagonista dell'Innovazione — A&T, Torino, 14 Febbraio 2025

Outline

We describe our European Project DrapeBot for automating Carbon Fiber Draping through the interaction between a Robot and a Human Operator:

- We quickly reference to our AI approach which develops an Integrated Task and Motion Planning (TAMP) system

- We shortly discuss how TAMP can deal with tasks involving a Human-Robot-Interaction (HRI) process

- After having illustrated an Architecture to implement TAMP, we point out five specific Challenges (CH1, …, CH5)) taken into consideration by our EU Project, with particular attention to two main aspects:

Safety and Ergonomics.

Integrazione di tecniche di Task e Motion Planning della IA per la sicurezza ed efficienza in un processo manufatturiero robotizzato.

La sinergia tra le capacità del robot e le competenze dell'uomo offre numerosi vantaggi nei processi industriali. Una corretta integrazione di Task and Motion Planning (TAMP), che tenga conto dell'interazione dell'utente con l'ambiente, è essenziale per massimizzare i benefici dei compiti assistiti dai robot e per garantire la sicurezza nei compiti collaborativi Human-Robot. Si illustrerà come esempio di applicazione, un processo robotizzato di drappeggio di strati di fibra di carbonio, con riferimento al progetto europeo DrapeBot, nel quale è stata migliorata la gestione della dinamicità e dell'incertezza data dall'introduzione di un operatore umano al fine di assicurare una maggiore sicurezza per l'operatore ed efficienza nel compiere il lavoro collaborativo

Integrating Task and Motion Planning Techniques for Security and Efficiency of Robotized Manufacturing Processes

The synergy between the robot's abilities and human expertise provides several advantages in the industrial processes. A proper integration of Task and Motion Planning (TAMP), considering the interaction of the user with the environment is essential to maximize the benefits of robot-assisted tasks and to ensure safety in collaborative Human-Robot tasks. However, the state of the art of the TAMP research field should be improved to overcome the limitations of the traditional TAMP approaches to be used in industrial scenarios. We illustrate a list of challenges that has been solved in order to improve to manage efficiently the dynamism and uncertainty given by introducing a human operator into a robotized process of draping fiber carbon plies, with reference to the granted European Project DrapeBot. The proposed TAMP architecture is presented to address the challenges described.

Introduction

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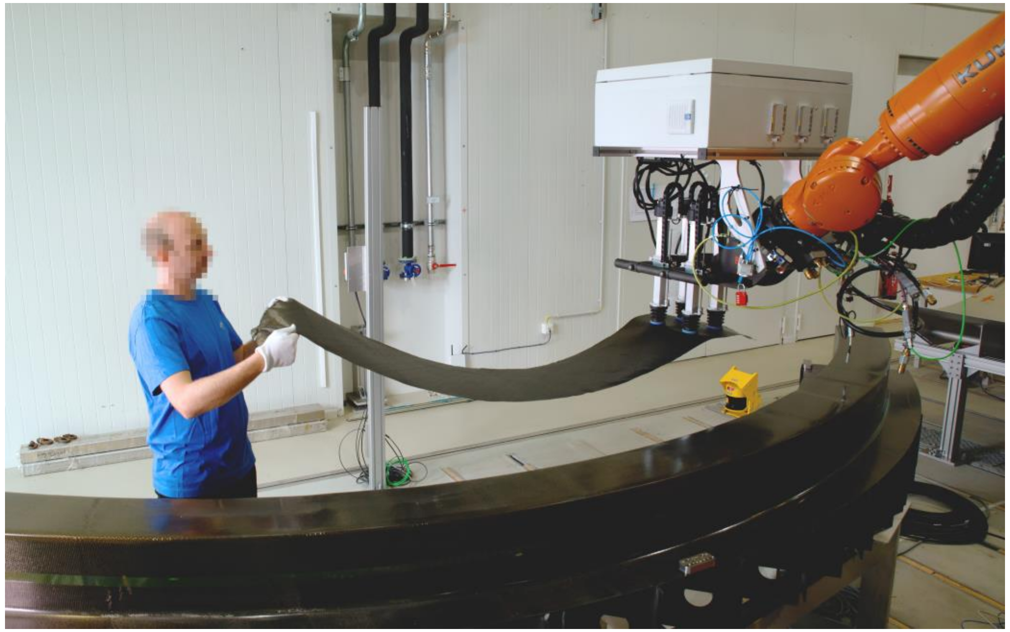
- Human-Robot cooperation in an industrial scenario is an important technological challenge
- The combination of human and robot capabilities enhances the industrial processes (Industry 5.0)



IT+Robotics | Università degli Studi di Padova | Department of Information Engineering, University of Padova | IAS-Lab | DrapeBot

Draping is a process used for about 30% of all carbon fibre composite parts to place layers of carbon fiber fabric in a mould. During this process the flat fabric distorts to fit to the shape of the mould. Ensuring the accuracy of draping in terms of position and fiber orientation while avoiding wrinkles is a challenging task.

DrapeBot Project runs Jan-2021 to Dec-2024

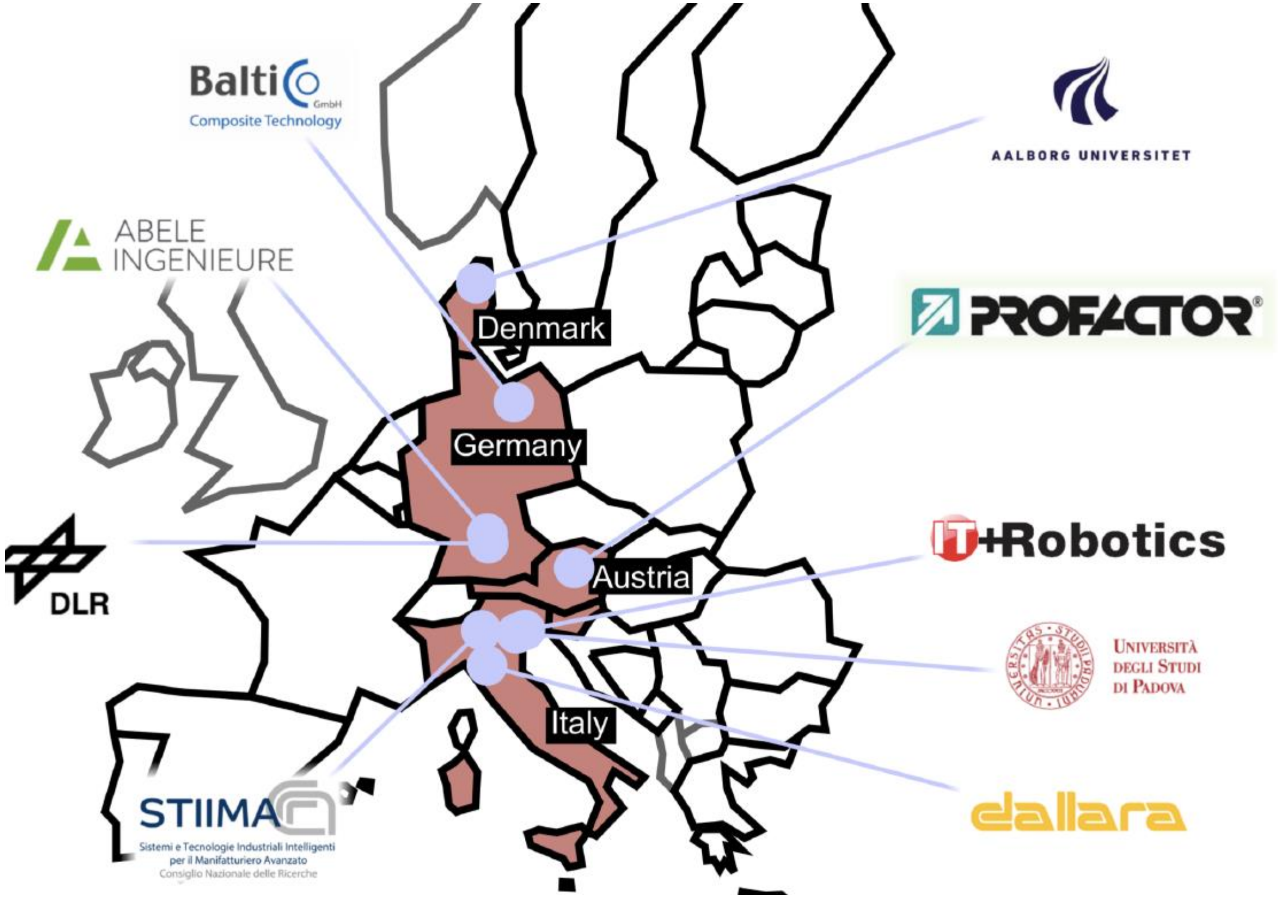
DrapeBot project aims at Human-Robot collaborative draping.

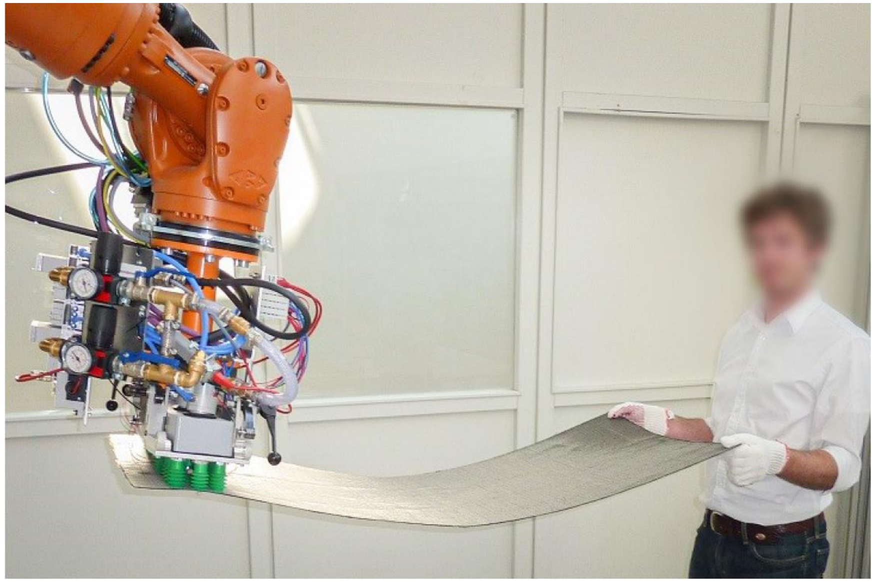
Robot assists during the transport of large material patches and to drape in areas of low curvature.

Human's role is to drape regions of high curvature.

DrapeBot develops a gripper system with integrated instrumentation, low-level control structures, and AI-driven human perception and task planning models, aiming at a smooth and efficient interaction between human and robot. Specific emphasis on trust and usability, due to sizes of involved robots.

Different phases of cooperative human-robot interactions



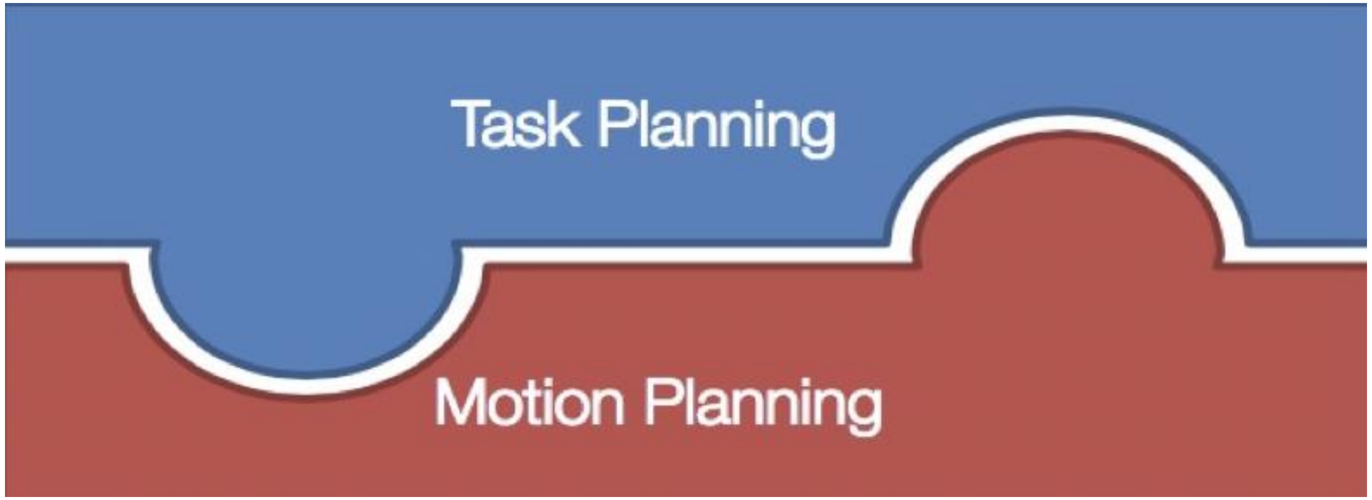


DrapeBot Consortium 2021-2024

Task and Motion Planning: Problem Definition

- Given an initial state of the robot and environment as well as a goal configuration, find a sequence of (higher-level) actions that changes the initial state to the desired one, such that it satisfy some desired goal constraints
- Motion Planning Problem
  - - how to move from one robot configuration to another
  - - it only considers the robot configuration space
- Task Planning Problem
  - It aims to solve complex tasks that involve a potentials large number of objects, and have long time horizon
  - The State Space includes all objects in environment

Task and Motion Planning: (TAMP) Problem Definition



Combine Task and Motion Planning:

- Task planner and motion planner cooperate
- Only geometrically valid plans are sent to the executor

Result: to enable robots to find the optimal sequence of actions and corresponding trajectories to achieve the assigned task.

Integrating Symbolic Reasoning with Action Execution

Complex manipulation tasks require careful integration of Symbolic Reasoning and Motion Planning:

TAMP is even more challenging if the workspace is non-static, e.g. due to human interventions and perceived with noisy non-ideal sensors.

RH-TAMP is an on-line planning algorithm that combines a geometric reasoning module and a Motion Planner over a Receding Horizon that takes inspiration from the Model Predictive Control Method for integrating Task And Motion Planning.

Our approach iteratively solves a reduced planning problem over a receding window of a limited number of future actions during the implementation of the actions.

Thus, only the first action of the horizon is actually scheduled at each iteration, then the window is moved forward, and the problem is solved again. This process allows to naturally take into account potential changes in the scene while ensuring good runtime performance.

Receding Horizon TAMP (RH-TAMP)

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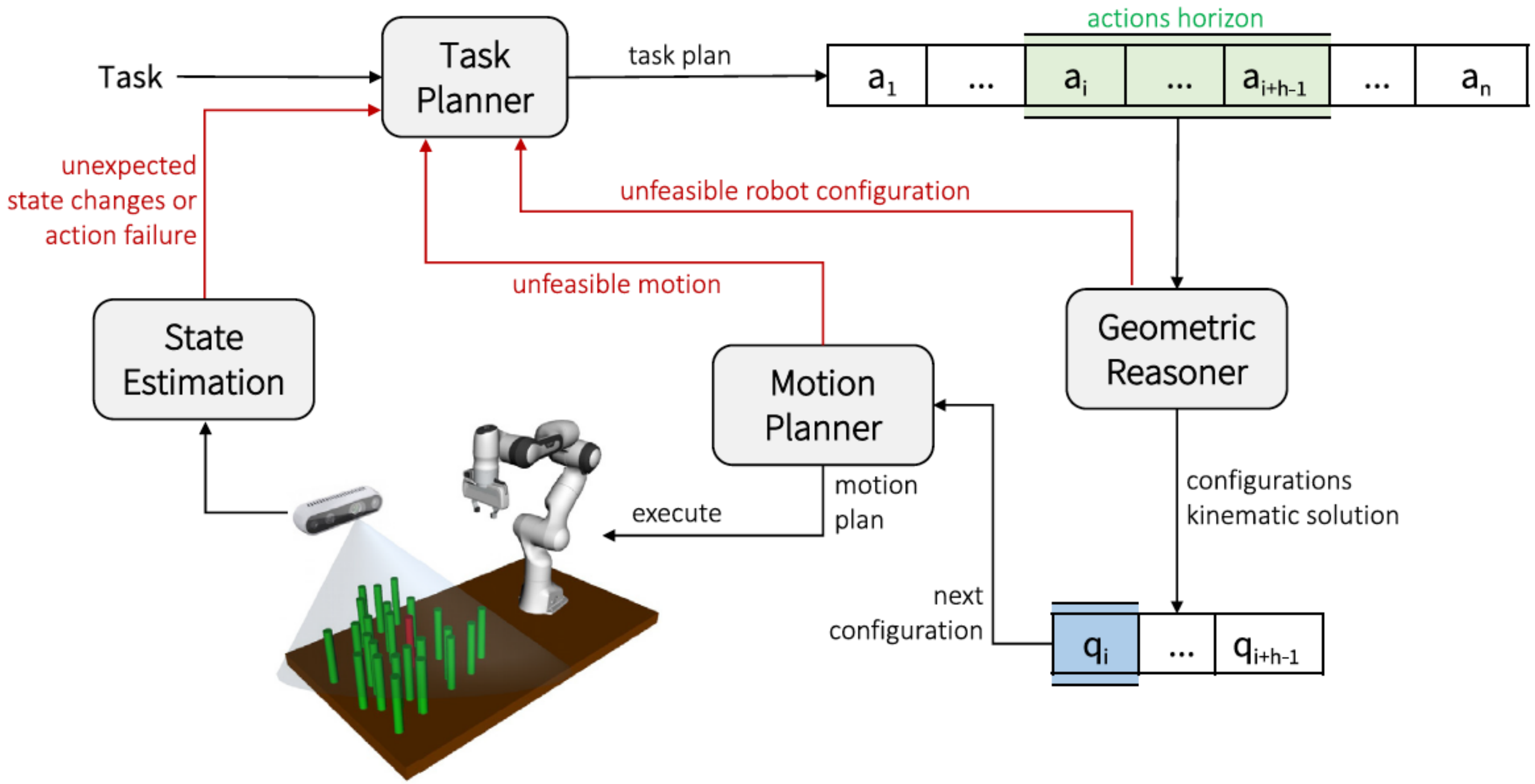

N. Castaman, E. Pagello , E. Menegatti, and A. Pretto *Receding Horizon Task and Motion Planning in Dynamic Environments*. Robotics and Autonomous Systems. Vol. 145, 2021

Cited in "Recent trends in task and motion planning for robotics: a Survey" by H. Guo et al., ACM Computing Survey 2023

A Real Industrial Application: Draping of Carbon Fiber Parts

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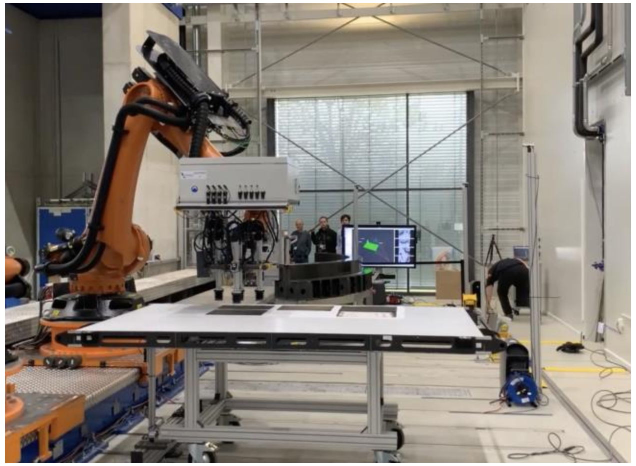
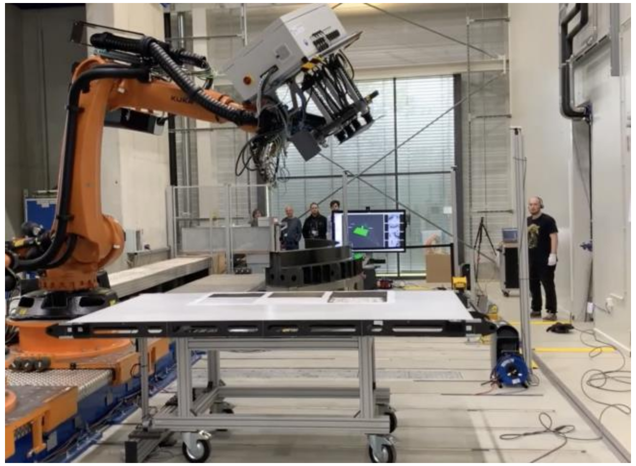
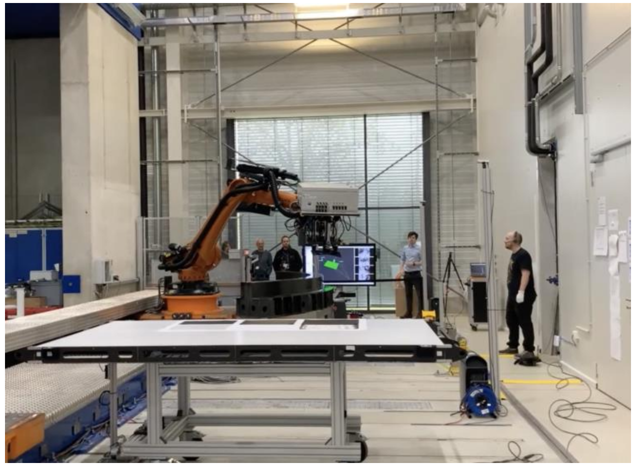
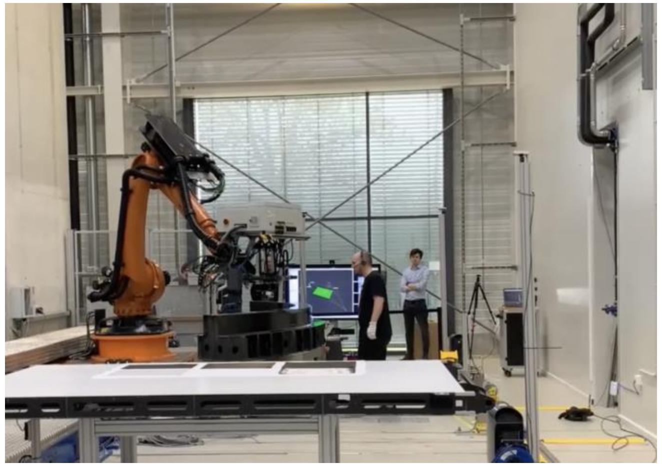
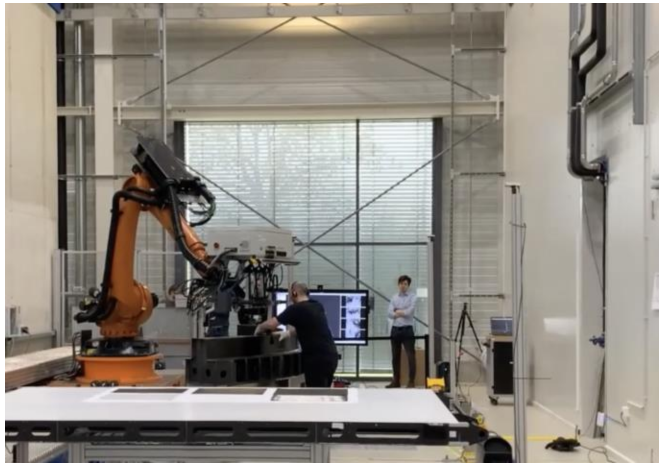

European Project DrapeBot: https://www.drapebot.eu/

Applying TAMP in HRI

In Human-Robot Interaction (HRI) combination of human dexterity with precision and strength provided by robots can lead to innovative and performing solutions.

The unpredictability of human presence needs to be integrated into TAMP, exploiting perception and sensorization: a TAMP framework can integrate H-R capabilities, by computing a feasible actions sequences and sharing them between humans and robots.

Enhancing TAMP's State of the Art

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TAMP Classical Scenario versus TAMP Scenario with H-R-I

- Deterministic environment
- Fully-observable state
- Static scenario
- Only robot
- Benchmark exist

Non-deterministic environment
Partially-observable
Dynamic scenario
Unpredictable human actions
Human in-the-loop
Cooperation & capabilities integration
No benchmark available

Task & Motion Planning: Architecture Overview

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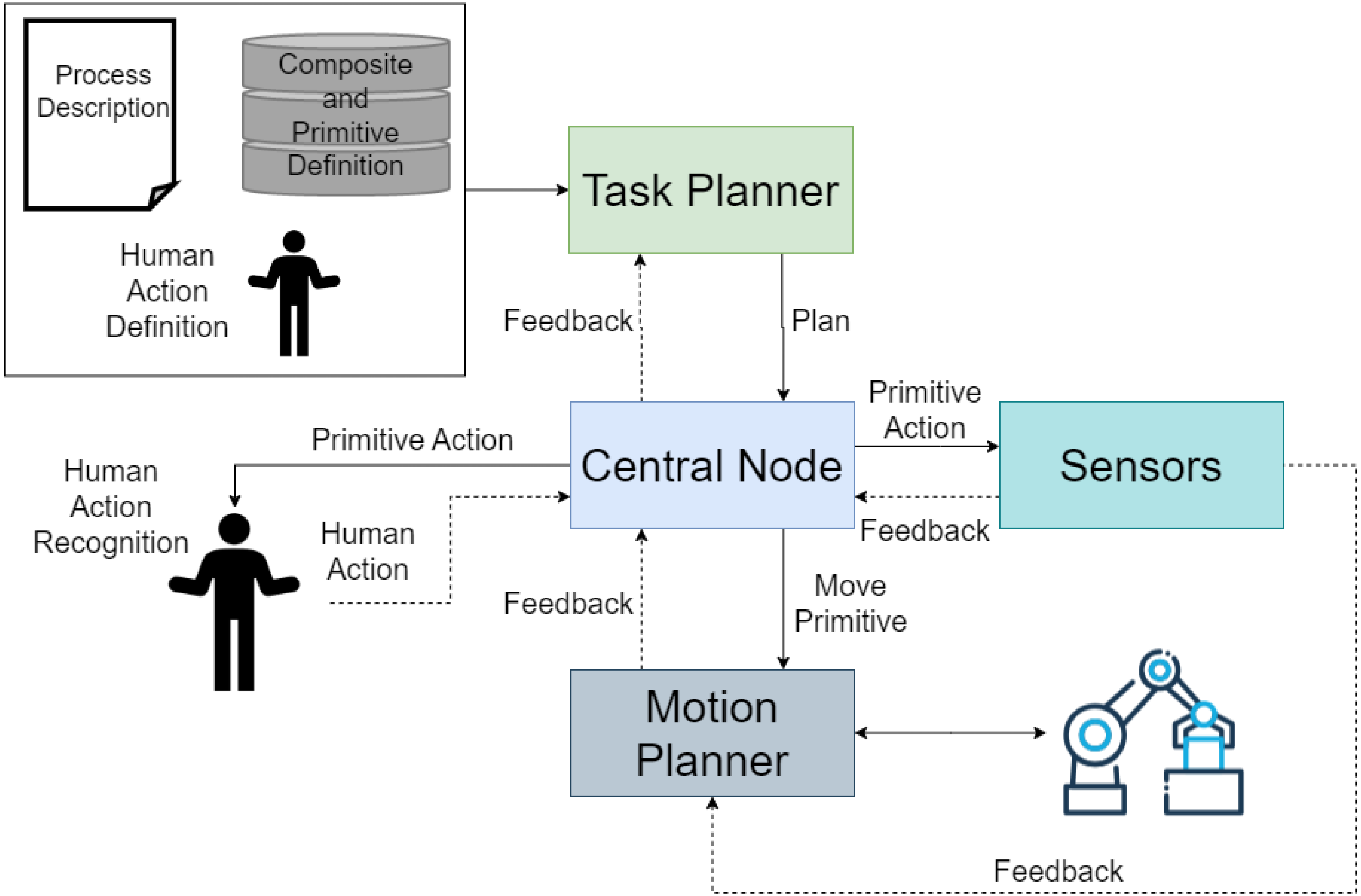

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Detecting the Challenges

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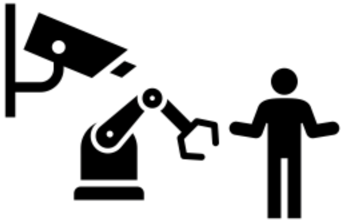
Collaboration

CH1-CH3:
- Cognition
- Skill and Ability
- Ergonomic

Safety

CH4:
- Safe Zones



Monitoring

CH5:
- Effort (affected by uncertainty and unpredictability)

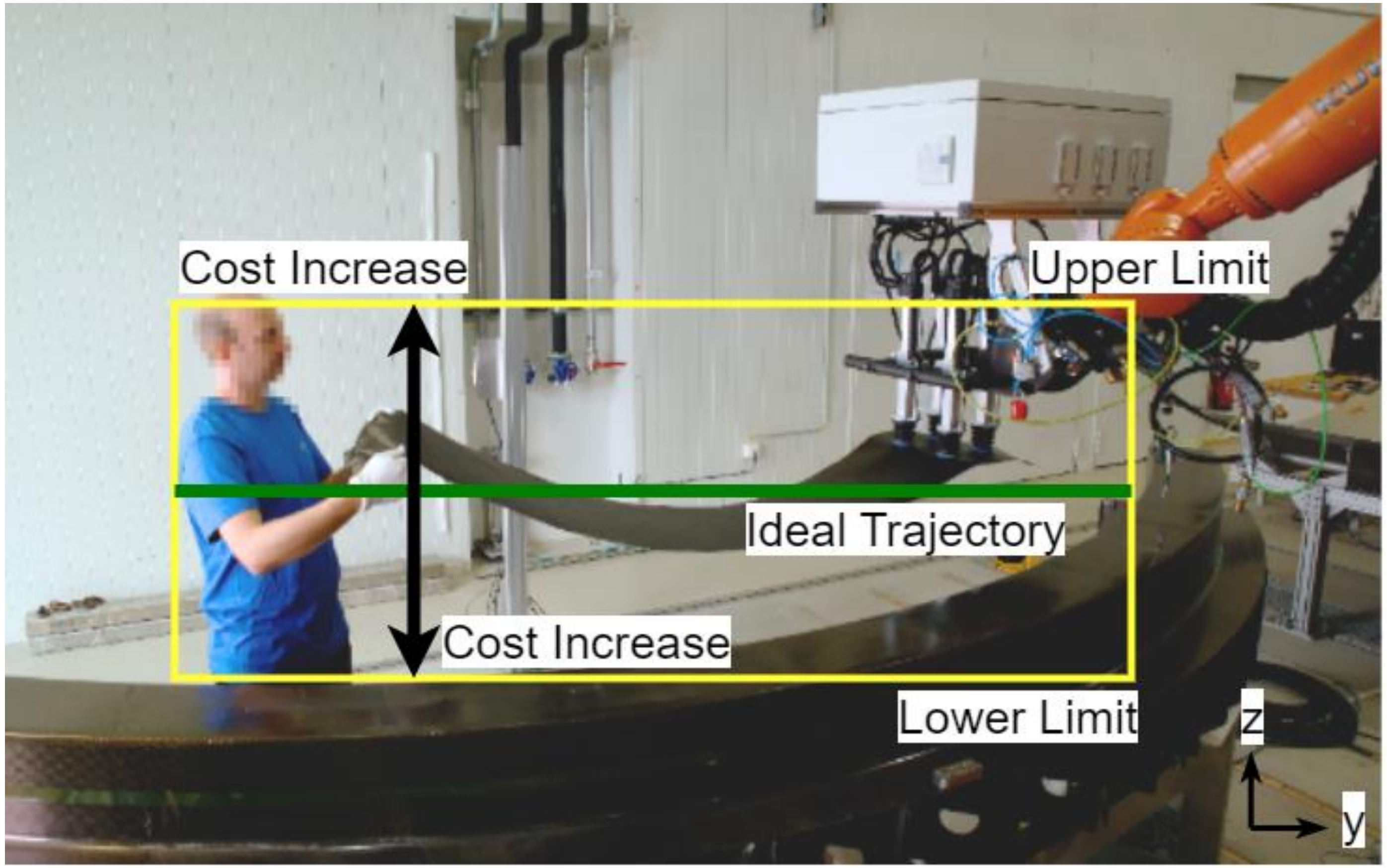
Gottardi, A., Pagello, E., Castaman, N., & Menegatti, E., ***Human-Robot Task and Motion Planning in an Industrial Application***, *IEEE/RSJ Workshop on Task and Motion Planning: from Theory to Practice. Detroit, 2023*

Motion Planner: an Ergonomic RRT

The planner must consider human limitations, emphasizing ergonomic constraints based on the operator stature [CHL3].

We modified the learning phase of Rapidly-exploring Random Tree (RRT) algorithm, to consider the human operator

it takes into account the human physical properties (e.g. heights, arms position, etc.) to create a feasible node that keeps the operator's pose ergonomic



Motion Planner: Safety constraints

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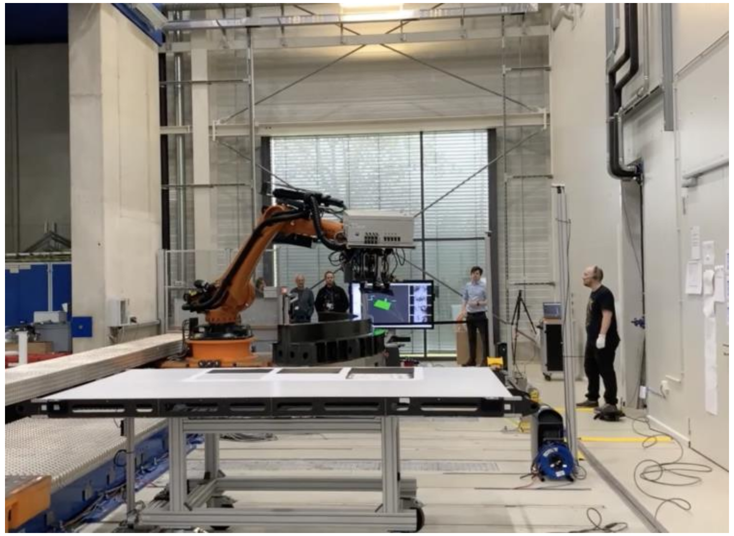
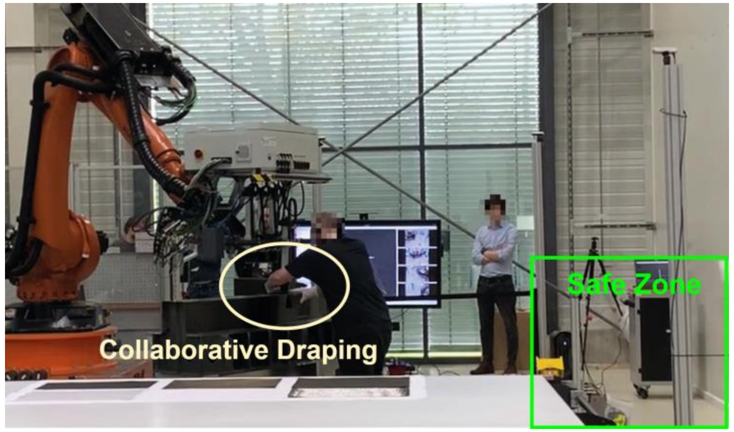
To ensure operator safety [CHL4], *Safe Zones* are introduced to restrict robot entry, assuring operator freedom to move caring his safety



Safe zones are of two types:

STATIC and DYNAMIC

Motion planning algorithm considers these zones to compute non-collaborative motions.



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Save the dates

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April 14 to 17, 2025. Palermo

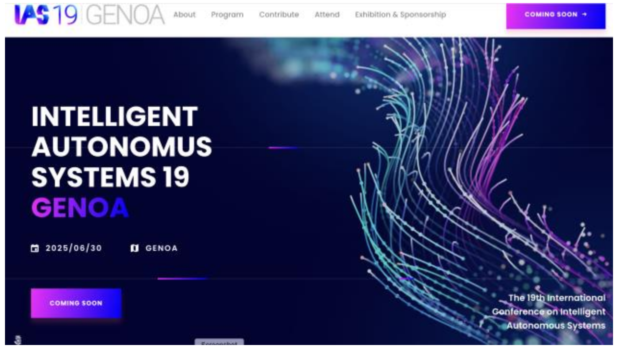
https://www.simpar2025.org/

7th SIMPAR *(IEEE International Conference on Simulation, Modeling and Programming of Autonomous Systems)*

June 30 to July 04, 2025. Genova

https://ias-19.org/

IAS-19 *(International Conference on Intelligent Autonomous Systems)*



September 02 to 05, 2025 Padova

ECMR-2025 European Conference on Mobile Robots *https://ecmr2025.dei.unipd.it/*

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Publication List

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- N. Castaman, **E. Pagello** , E. Menegatti, and A. Pretto *Receding Horizon Task and Motion Planning in Dynamic Environments*. Robotics and Autonomous Systems. 2021
- **Gottardi, A.**, Terreran, M., Frommel, C., Schoenheits, M., Castaman, N., Ghidoni, S., & Menegatti, E. *Dynamic Human-Aware Task Planner for Human-Robot Collaboration in Industrial Scenario.* IEEE European Conference on Mobile Robots (ECMR-2023)
- Miotto, N., **Gottardi, A.**, Castaman, N., & Menegatti, E. *Collision-free Volume Estimation Algorithm for Robot Motion Deformation.* 21st IEEE Int. Conference on Advanced Robotics (ICAR-2023)
- **Gottardi, A.**, **Pagello, E.**, Castaman, N., & Menegatti, E. *Human-Robot Task and Motion Planning in an Industrial Application*. IEEE/RSJ IROS Workshop on Task and Motion Planning: from Theory to Practice. 2023
- Terreran, M., **Gottardi, A.**, Menegatti, E., & Ghidoni, S. *Human-Robot Collaborative Transportation via Distance-based Role Allocation for Precise Positioning of Flexible Materials.* 29th Int. IEEE Conference on Emerging Technologies and Factory Automation (ETFA-2024)
- Campagna, G., Frommel, F., Haase, T., **Gottardi, A.**, Villagrossi, E., Chrysostomou, D., & Rehm, M. *Fostering Trust through Gesture and Voice-Controlled Robot Trajectories in Industrial Human-Robot Collaboration.* IEEE Int. Conference on Robotics and Automation (ICRA-2024)

Aknowlegment

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Special thanks to **Stefano Ghidoni**, Responsible of the Unit at the Dept. of Information Engineering of the University of Padua, and **Stefano Tonello**, Responsible of the Unit at IT+Robotics Srl.

We also thank the valuable contribution of **Nicola Castaman**, **Emanuele Menegatti**, and **Matteo Terreran**.

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Conclusions

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* We stressed the challenges that arise when applying an integrated Task and Motion Planning approach to an industrial manufacturing process where a robot must interact with a human operator

* Two issues play a main role: Safety and Ergonomics

* Our approach has been tested and validated within the European Project DrapeBot for Automating Carbon Fiber Draping process in cooperation of a robot with a human

Thanks for attention !