



**Politecnico
di Torino**

Dipartimento
di Elettronica
e Telecomunicazioni



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Robotics for innovation @DET

La quarta di una serie di vetrine per mettere in contatto le esigenze delle imprese con le soluzioni tecnologiche sviluppate dal DET

**29 Novembre 2024 ore 9:00 | DET, Politecnico di Torino
Sala Maxwell (5° piano), C.so Castelfidardo 42/A, Torino**

PROGRAMMA

- 9.00 - 9.15** Presentazione centro interdipartimentale PIC4SeR
- 9.15 - 10.45** Presentazione di soluzioni da parte dei docenti DET
- 10.45 - 11.00** Coffee break
- 11:00 - 11.40** Presentazioni di problemi aperti da parte di aziende
- 11.40 - 11.50** Wrap-up

**Per dettagli e
registrazione:**



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The PIC4SeR Interdepartmental Centre on Service Robotics

M. Chiaberge



**Politecnico
di Torino**

PIC4SeR – Service robotics

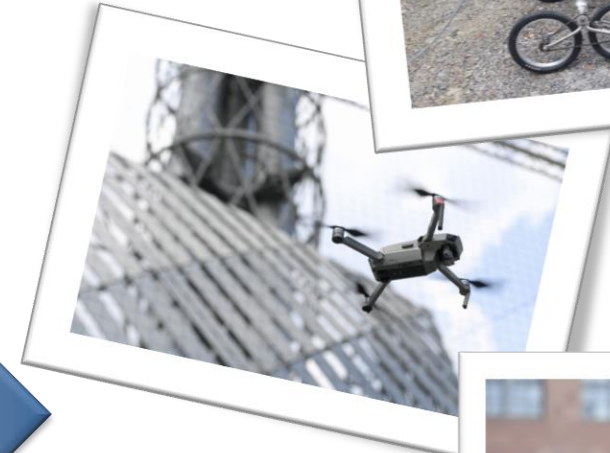


Industrial Robots

Key technologies shaping

PERCEPTION
COGNITION
ACTION

Future capabilities of robots



Service Robots

PIC4SeR – Enabling technologies

/Energy optimization

/GNSS navigation

/4G and 5G Networks

/Path planning

/Cooperative positioning

/SDR receivers

/Sensor integration

/Locomotion platforms

/ROS2

/Soft robotics

/Multimedia communication

/Control

/Coding

/Human Machine Interaction

/Internet of Things

/Machine Learning

/Artificial Intelligence

/Interaction visualization

/Data fusion

/Interaction design

/Edge-Fog-Cloud Computing

/System Co-Design

/Ethics

/Co-living Design

/Embedded Computing

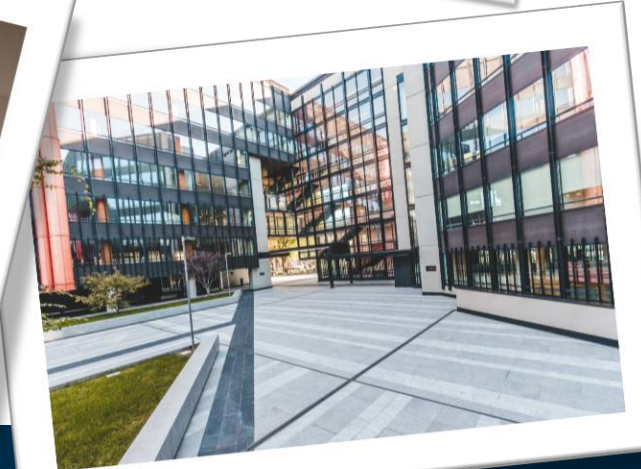
PIC4SeR – Why?

- Many of the current research, innovation and development in the service robotic field, can be classified as **disruptive technologies**
- Several uncorrelated research projects and industrial partnerships **must be harmonized** and coordinated to optimize the results
- To start a **common workplace**, a common knowledge and a common language
- To develop an **integrated approach** and technology development process in this booming area
- To help PoliTO reaching a **critical mass** in this sector (instead of several scattered initiatives)
- To **link together** technology needs coming from several industrial partners
- To start **interdisciplinary didactic activities** in this area
- To join several international research communities **with a unique “face”** and coordinated research proposals



PIC4SeR in pills

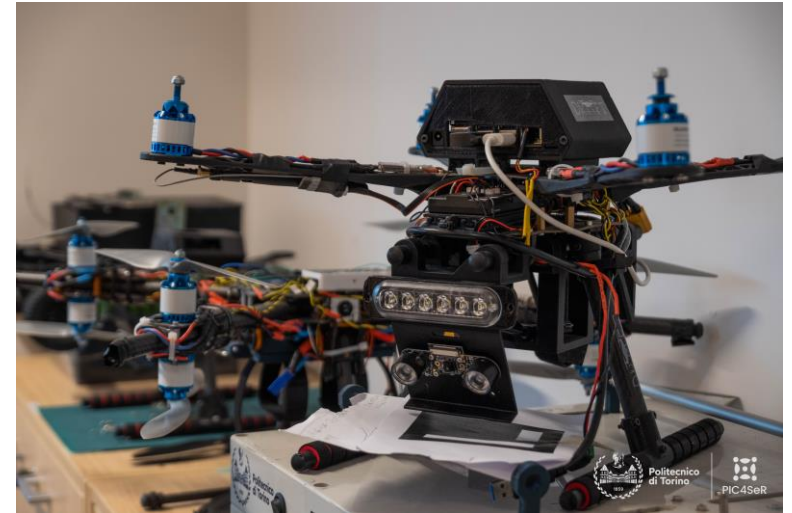
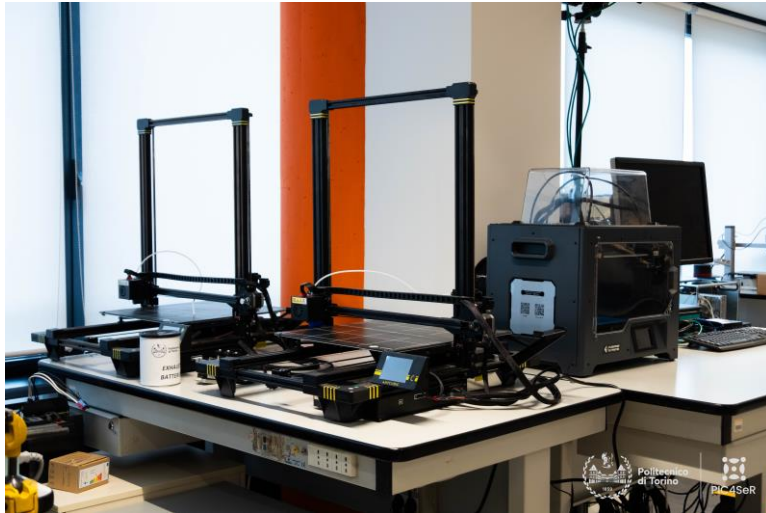
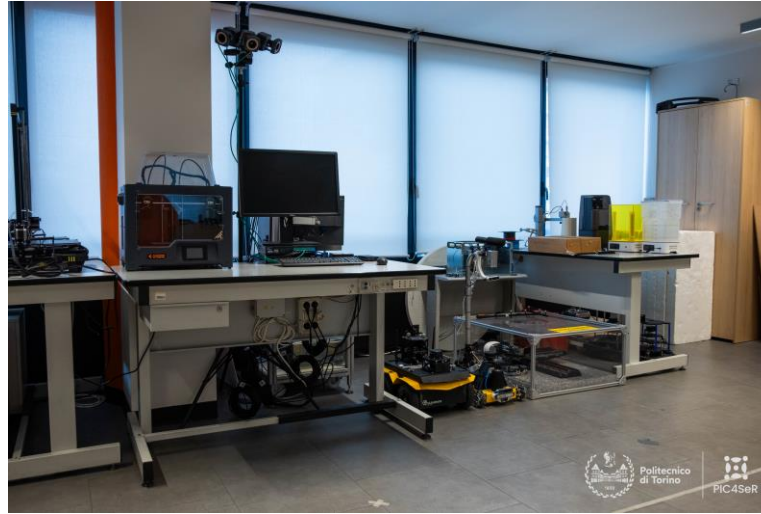
- **5 PoliTO departments**
 - DET (Electronics & Telecoms)
 - DAUIN (Informatics & Control)
 - DIMEAS (Mechanics & Aerospace)
 - DIATI (Geomatics & Photogrammetry)
 - DAD (Design & Cultural Heritage)
- **56 people** involved
 - 31 staff
 - 10 researcher
 - 15 PhD students
- **Location:** c/o COVIVIO building
 - C.so Ferrucci 112 – Torino
 - 580mq of labs and offices
 - indoor & outdoor **facilities** available for testing



PIC4SeR outdoor facilities



PIC4SeR indoor facilities



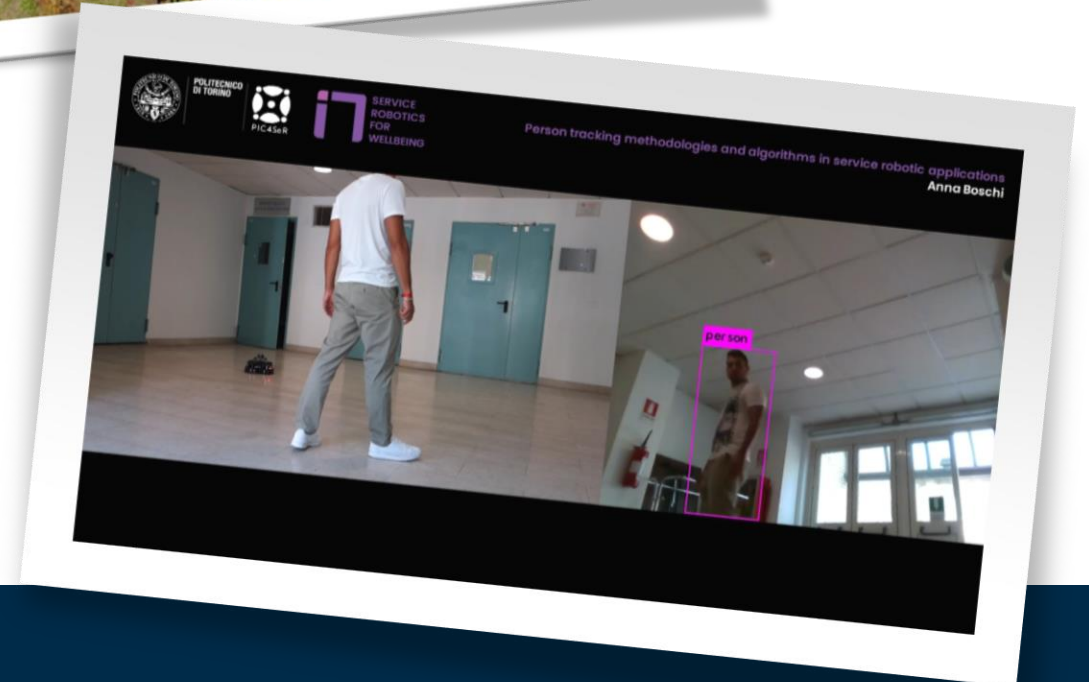
PIC4SeR – key application areas



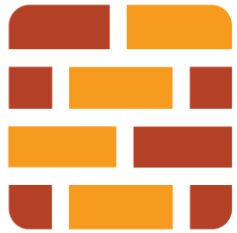
PRECISION
AGRICULTURE



SERVICE ROBOTICS
FOR WELLBEING



PIC4SeR – key application areas



CULTURAL
HERITAGE



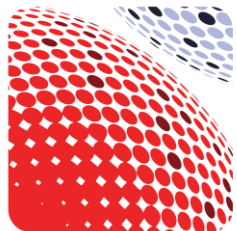
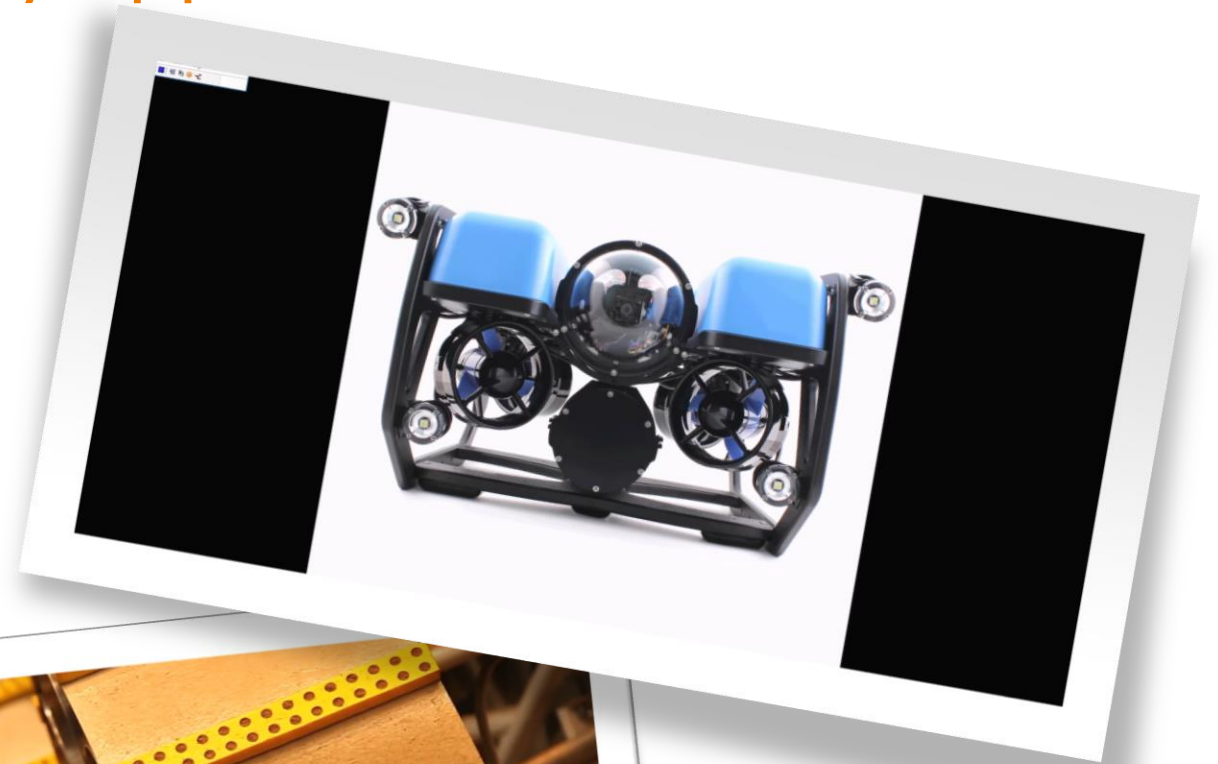
SMART CITY
SEARCH & RESCUE



PIC4SeR – key application areas



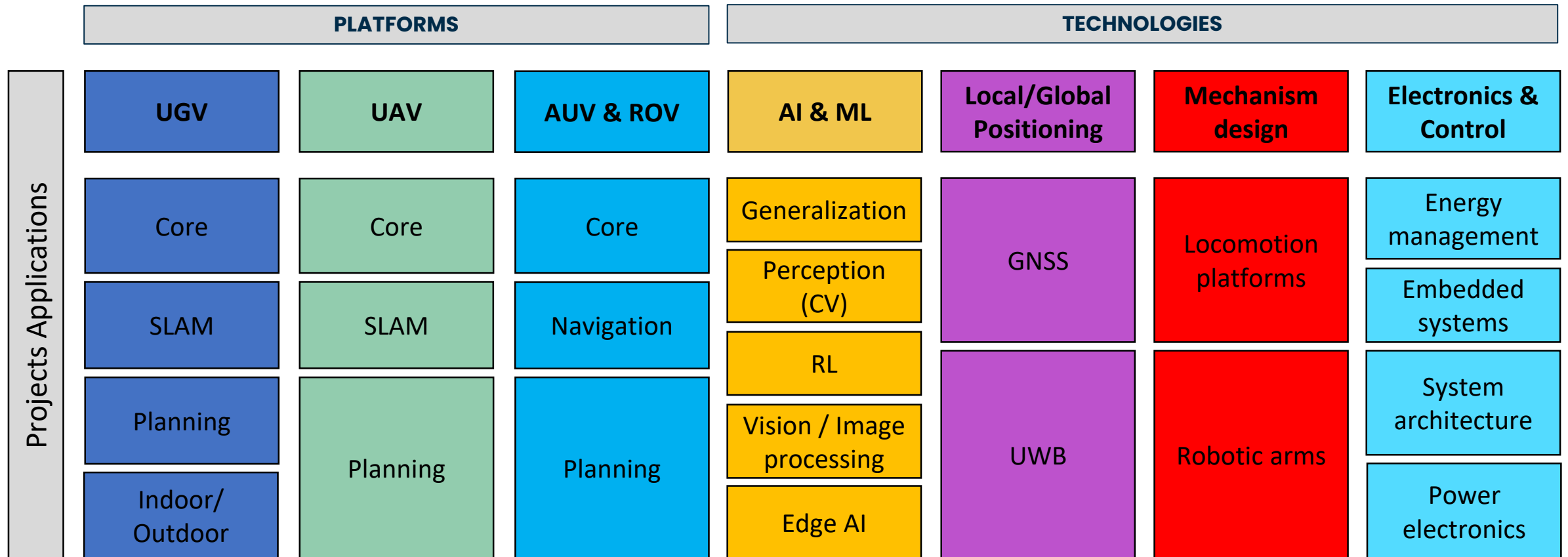
UNDERWATER

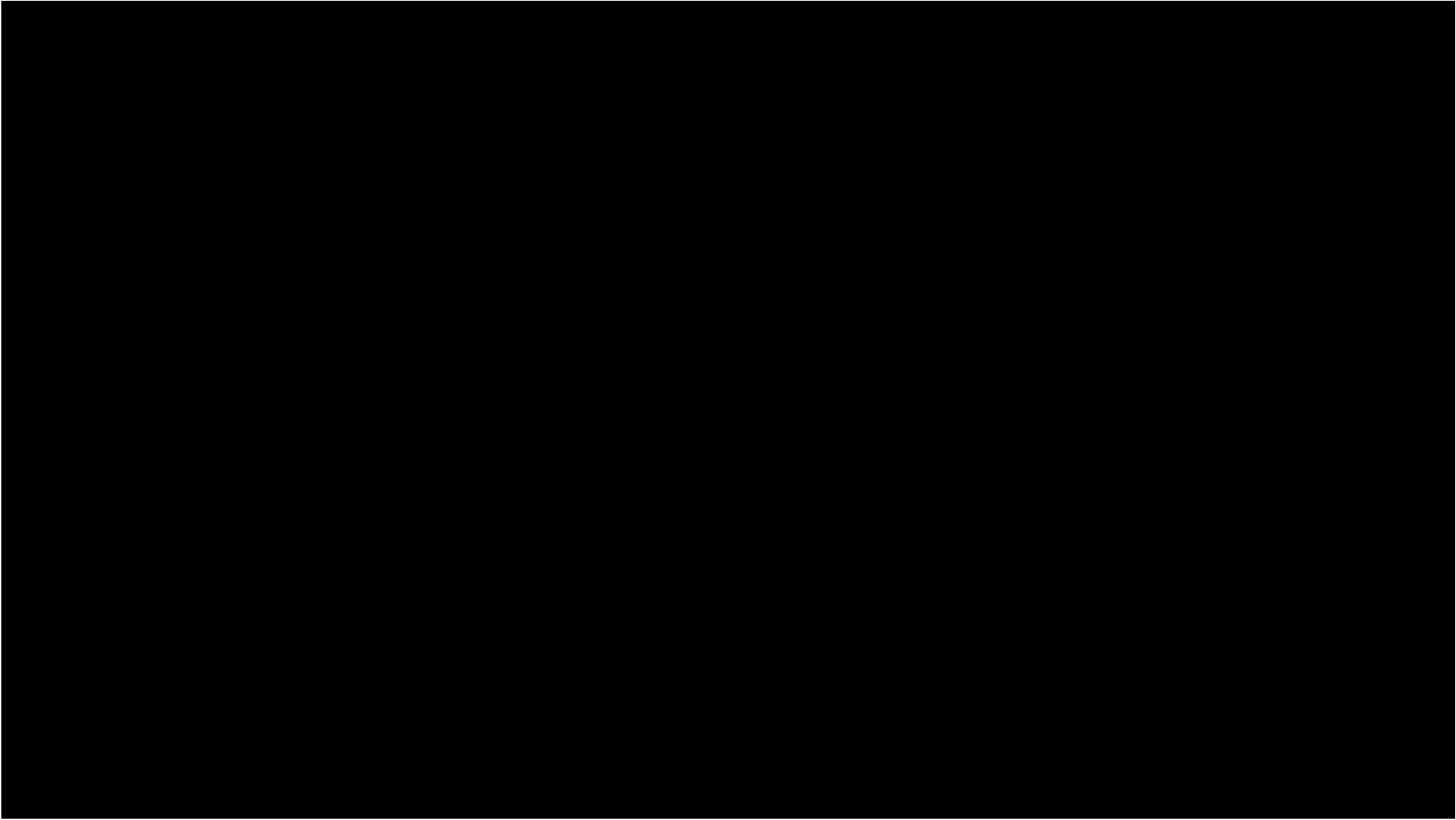


SPACE



PIC4SeR – Internal organization







Thank you!

www.pic4ser.polito.it

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Advanced navigation for real-world service robotics

Mauro Martini

PostDoc at PIC4SeR



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Service Robotics



SERVICE ROBOTICS
FOR WELLBEING



Indoor applications

Smart home-assistant robot
Autonomous multi-purpose platform for
offices, hospitals, etc



PRECISION
AGRICULTURE



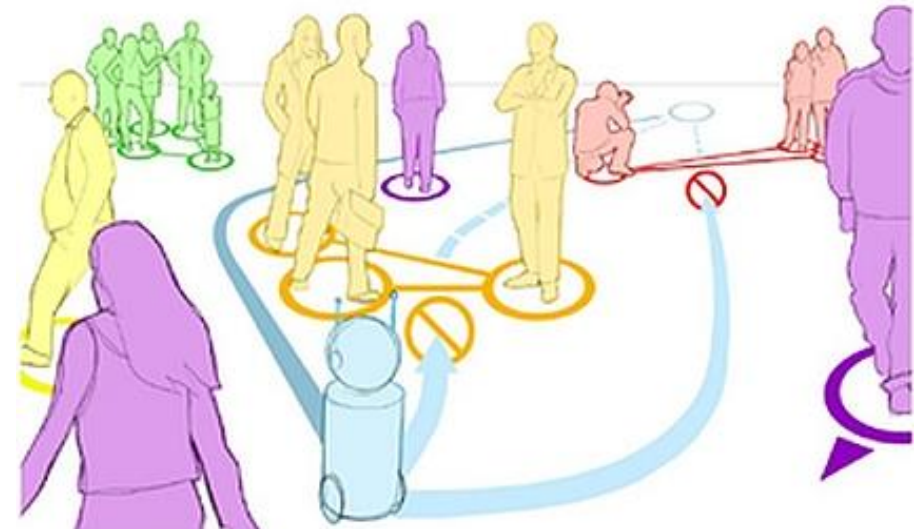
Outdoor applications

Precision Agriculture
Autonomous robot in row-based crops
(vineyards, orchards)

Social navigation

The context challenge

- **Social Rules** are not a formula!
- **Applications** for different types of robot include navigation in **crowded spaces**, autonomous parcel delivery, elderly assistance
- **Main challenge**: introducing social behaviours not considered by standard motion planners
- A **wide variety of social scenarios** and different behaviours



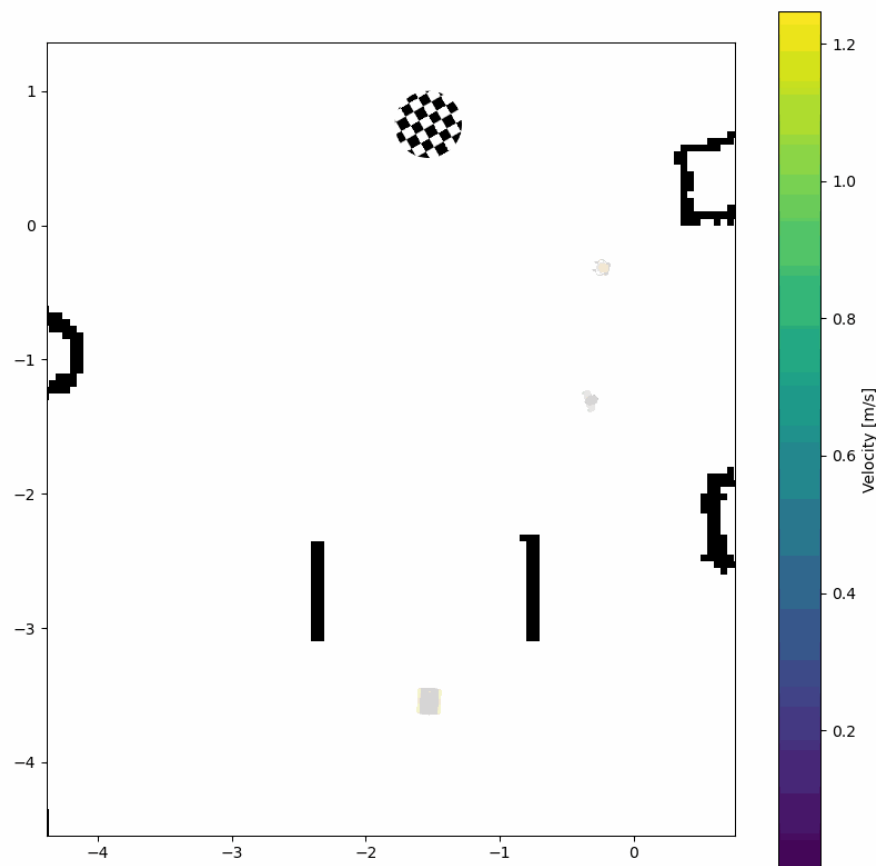
Applications

Wherever people are, social behaviors are required!

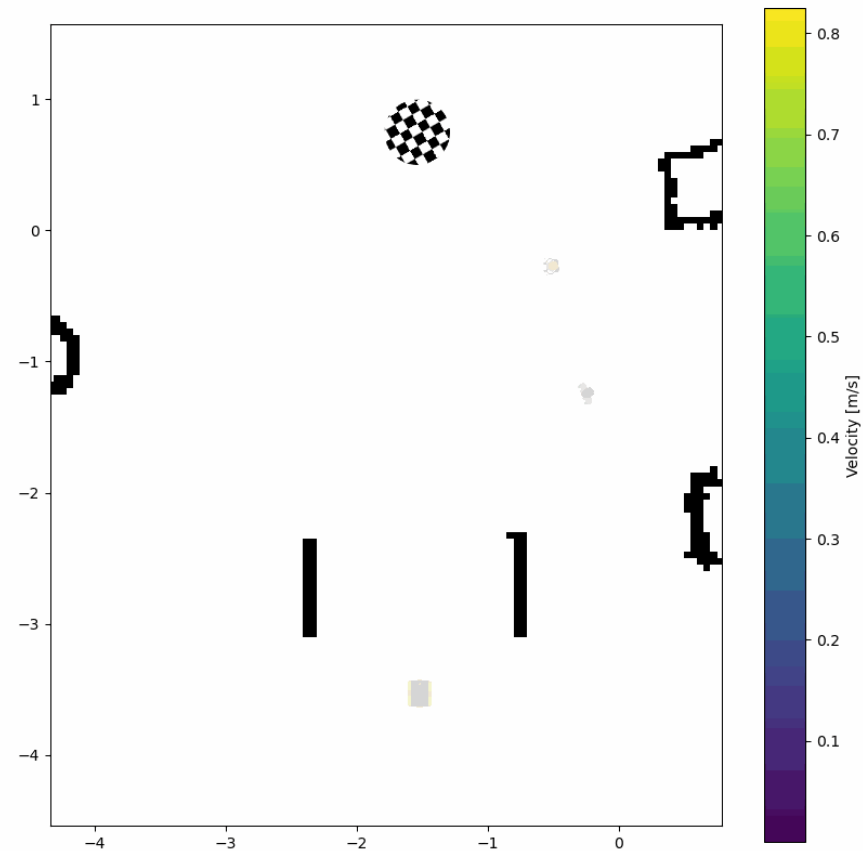
- **Environments:** offices, hospitals, schools, airports, domestic spaces, etc.
- **Tasks:** delivery, telepresence, monitoring and support.
- **Industry:** logistics, hybrid human-machine collaborative tasks



Fixed cost methods

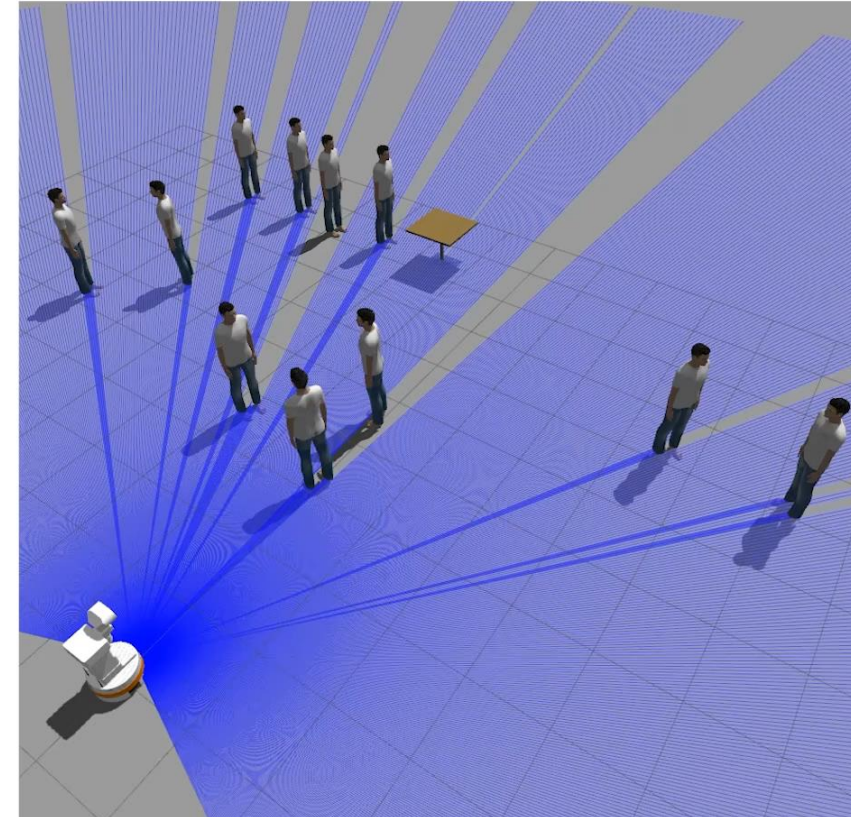
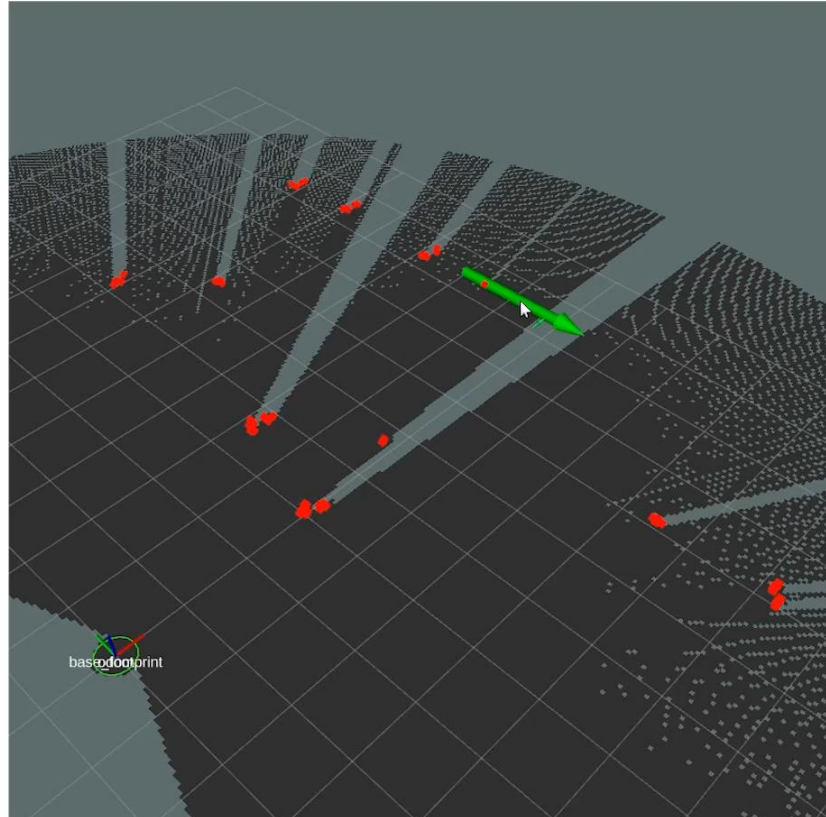


DWA w/ social cost

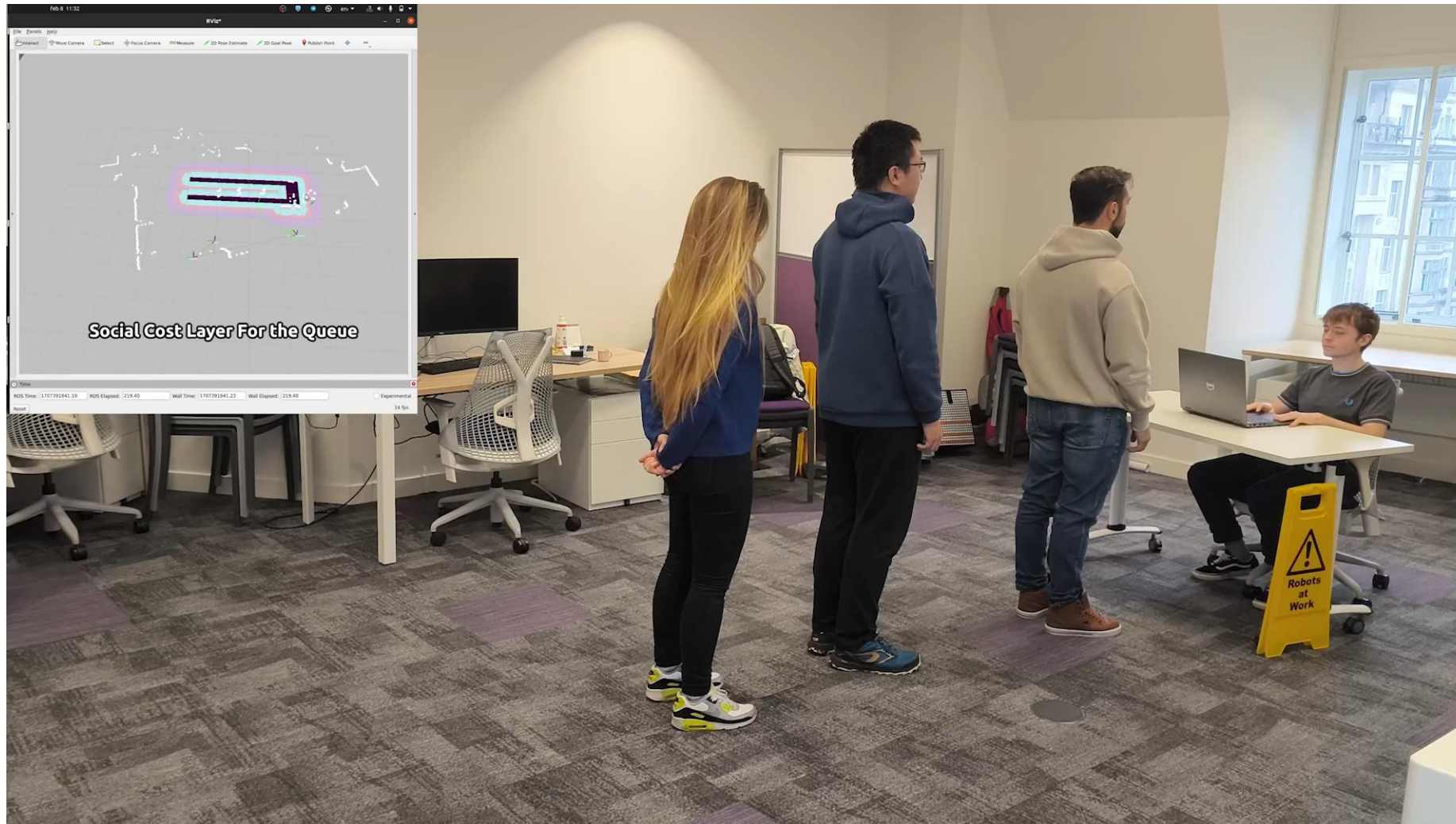


MPPI w/ social cost

Learning Social Cost Functions for Human-Aware Path Planning [IROS 2024]

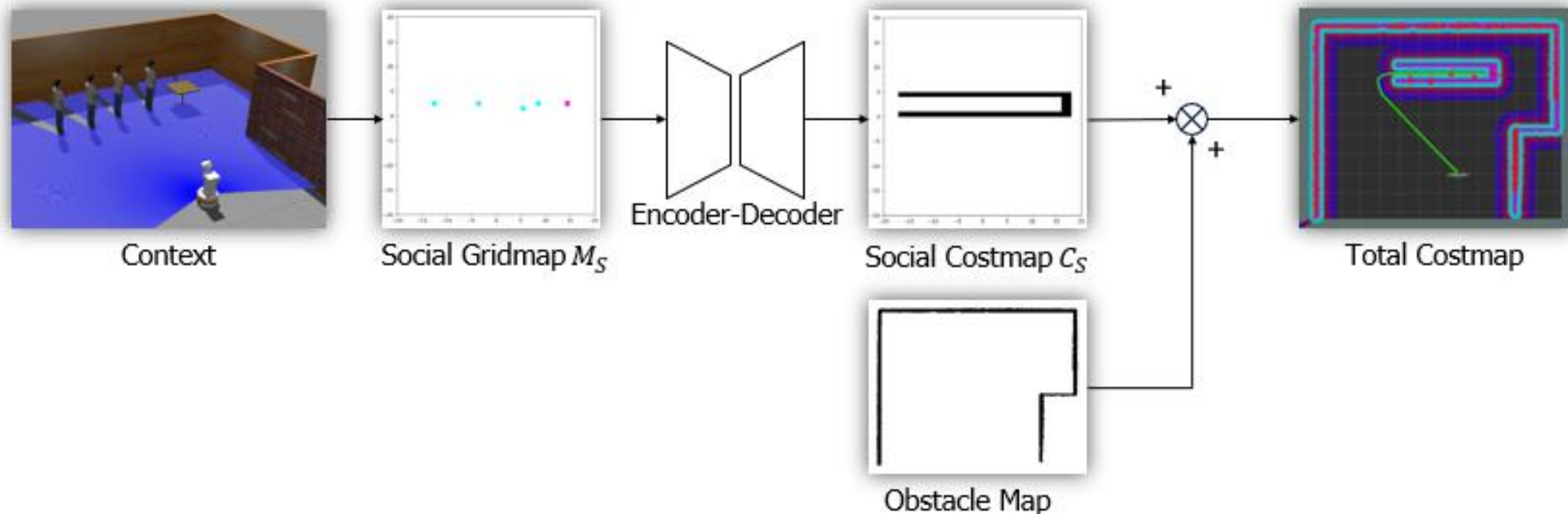


A robot in a queue?

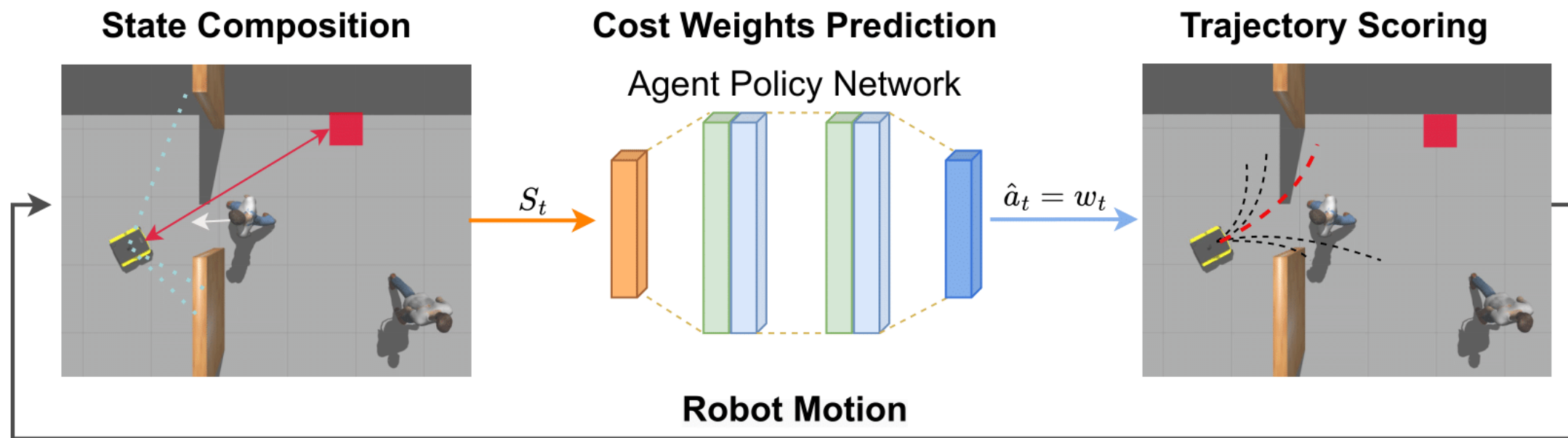


Social Cost Estimation for Planning

The **Encoder-Decoder deep neural network** produces the **Social Cost Map** for the path planner receiving the context information about people, obstacles and goal location.

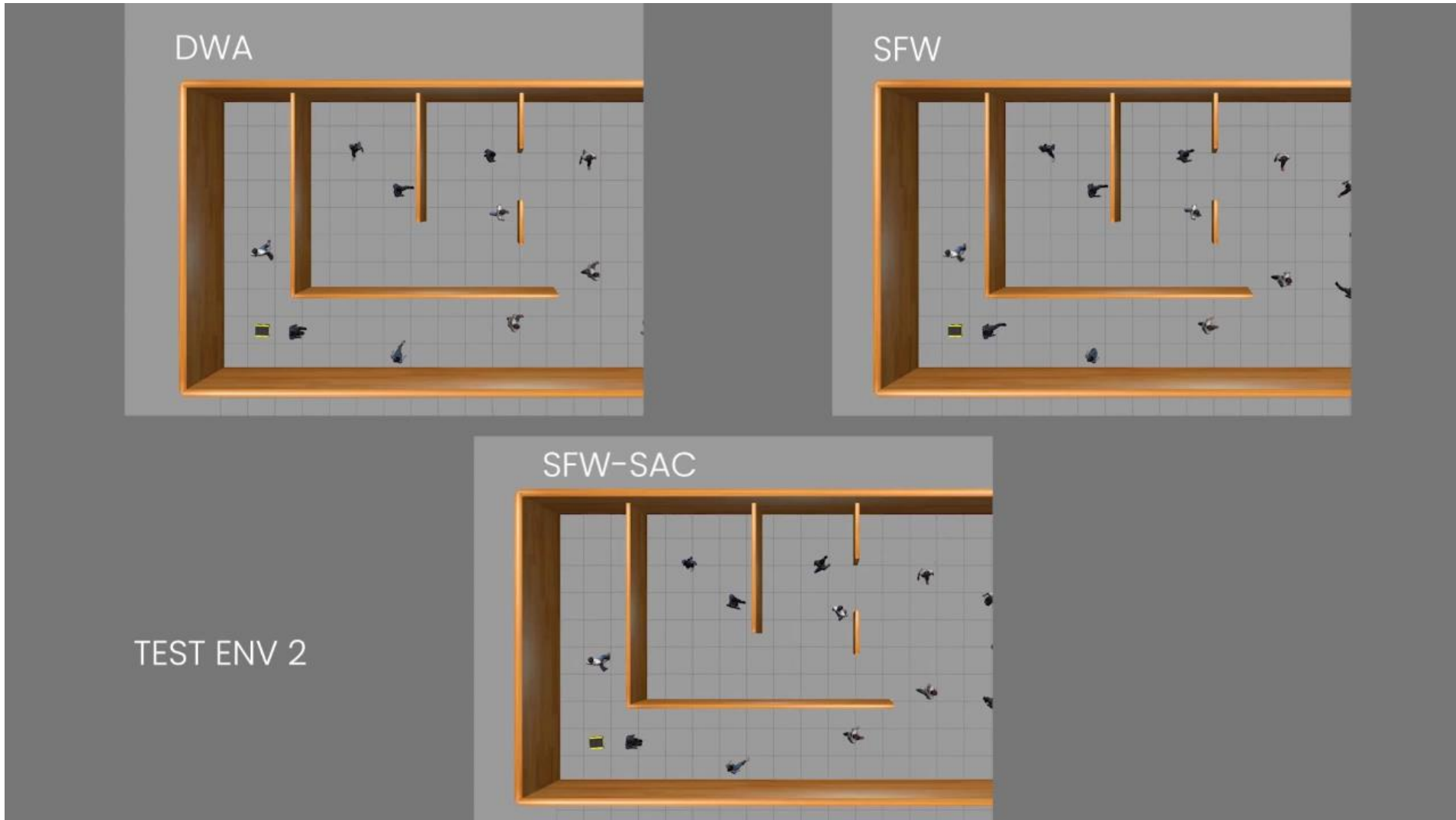


Adaptive Social Force Window Planner with Reinforcement Learning [IROS 2024]



- A **Deep Reinforcement Learning agent** learns a policy to dynamically set the weights of the cost function, based on the surrounding people and obstacles perceived
- The **social force window planner** computes the velocity commands based on the cost

Results in simulation



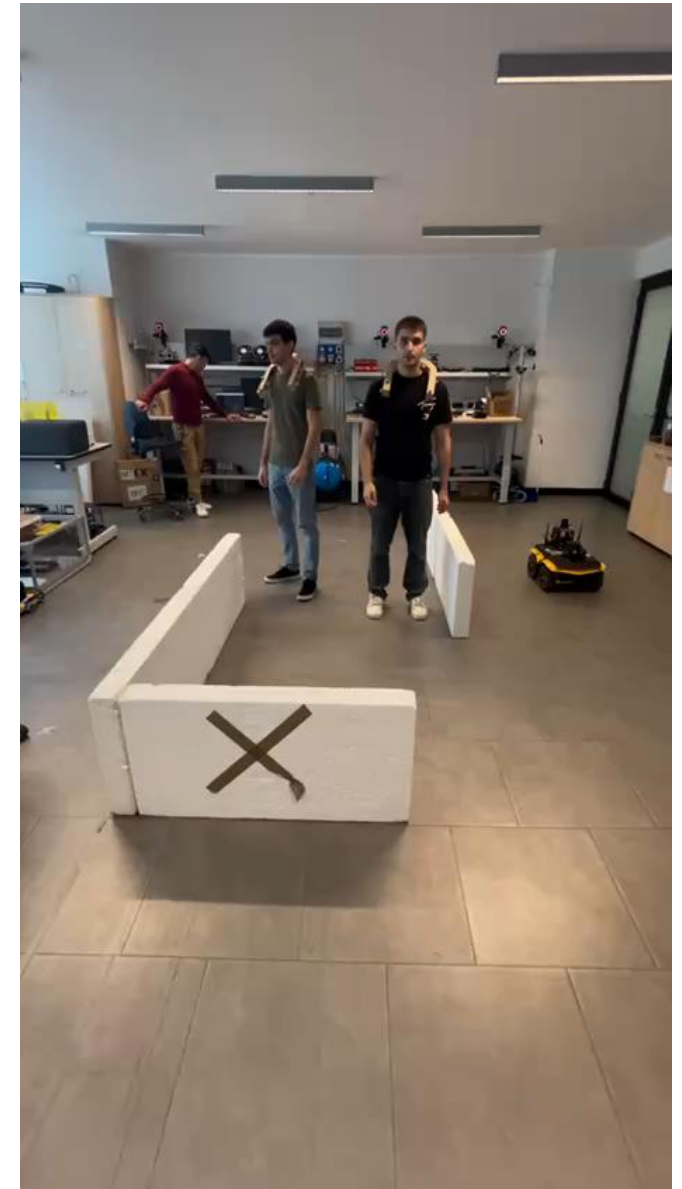
Lab experiments



Jackal robot with 2D Lidar



VICON cameras



Robotic Navigation in Row-based Crops

Context Challenges

- Reduce the **cost** and **complexity** of the platform (sensors, data)
- **Plants** reduce the **GNSS** signal reliability
- **Mapping** of each field: required to use classic global planning algorithms
- Hard manual **goal generation** for irregular fields shape

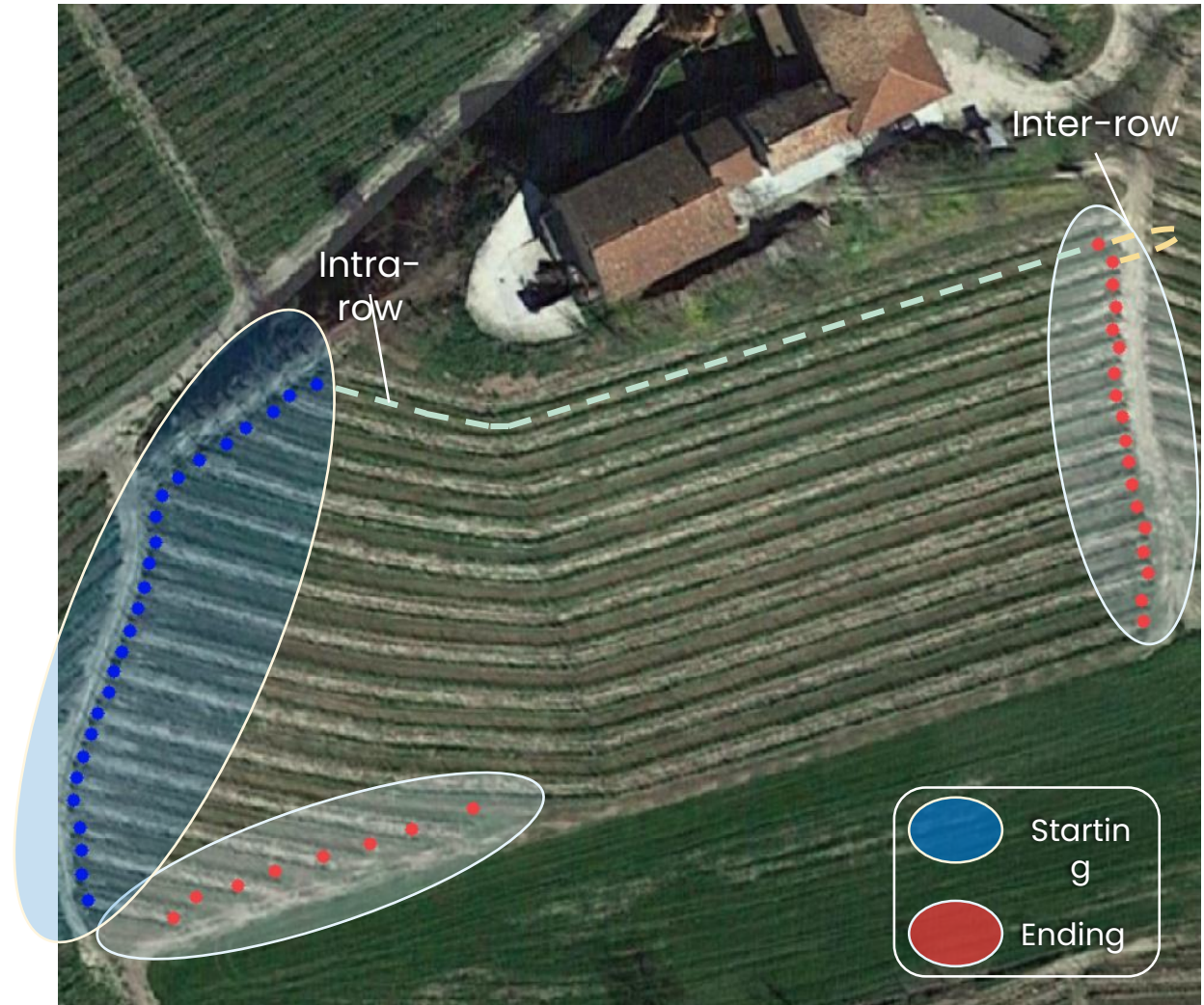


Scenario

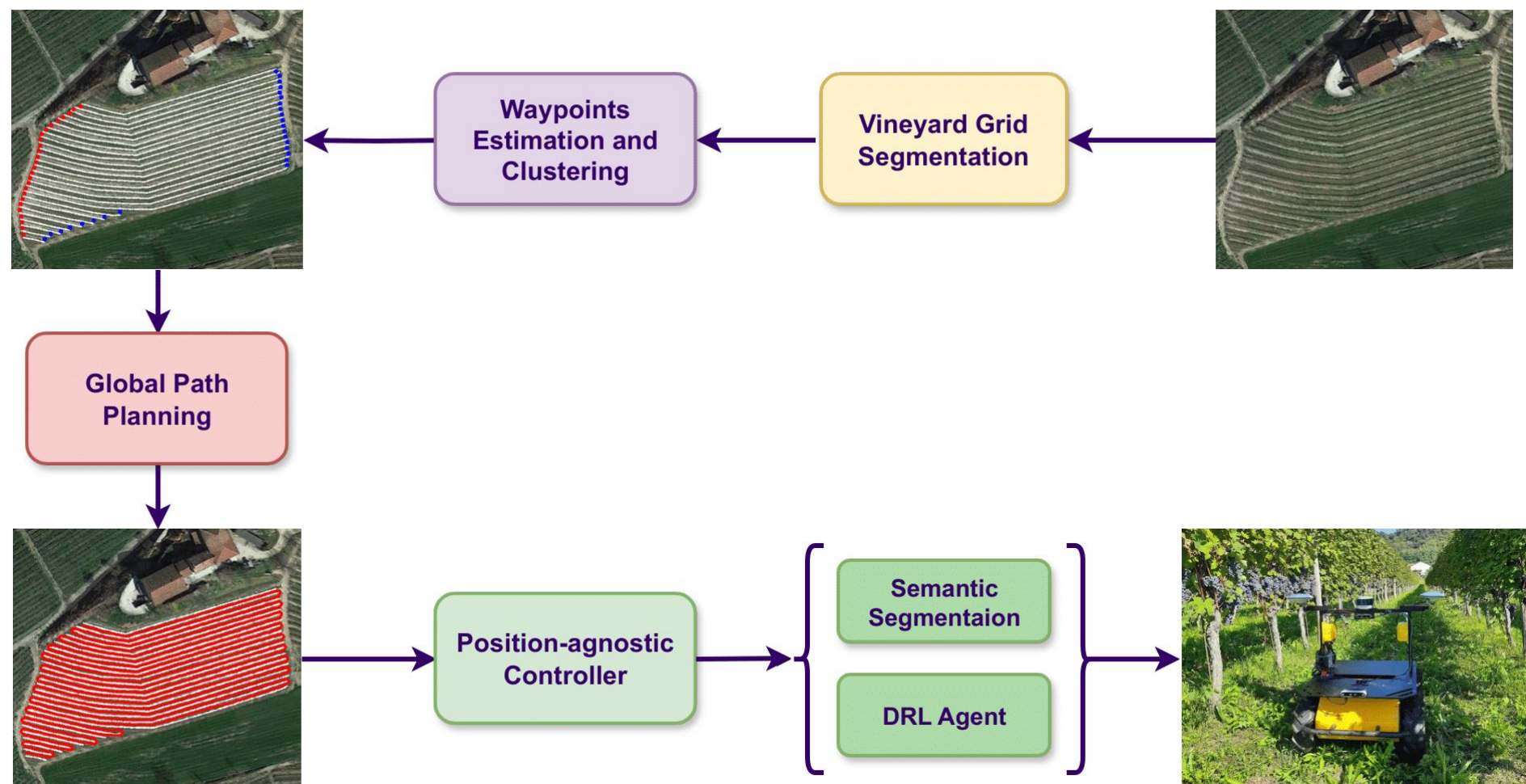
In a row-based crop we can identify two regions comprising the starting and ending points of each row.

A full-coverage robotic path can be divided into:

- **intra-row** segments: connect the starting region to the ending region
- **inter-row** segments: connect two starting or two ending points

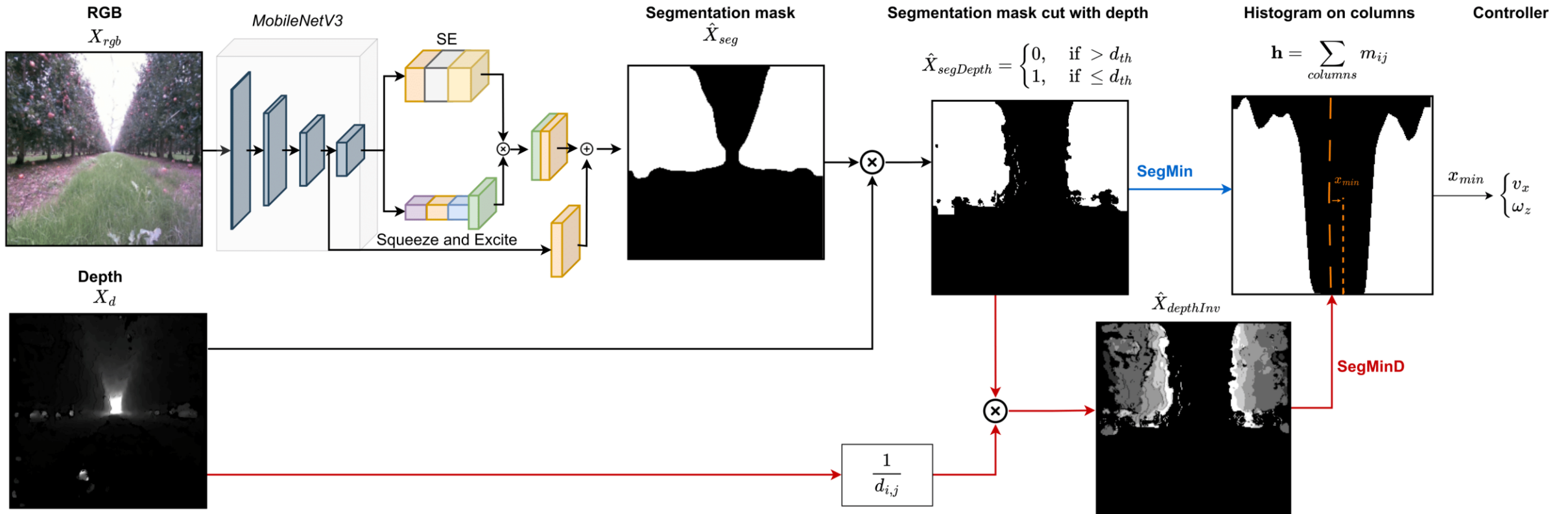


A Deep Learning pipeline for row-based crops navigation



S. Cerrato et al., "A Deep Learning Driven Algorithmic Pipeline for Autonomous Navigation in Row-Based Crops," in IEEE Access, vol. 12, pp. 138306–138318, 2024, doi: 10.1109/ACCESS.2024.3465873.

Autonomous Navigation for Precision Agriculture



Navone, A., Martini, M., Ostuni, A., Angarano, S., & Chiaberge, M. (2023, September). Autonomous Navigation in Rows of Trees and High Crops with Deep Semantic Segmentation. In *2023 European Conference on Mobile Robots (ECMR)* (pp. 1-6). IEEE.

Real-world navigation results

Real-time inference performance of the semantic segmentation network

Low-cost Hardware

- laptop CPU (Intel i7)
- RGB-D camera Intel RealSense D435 (30 fps)

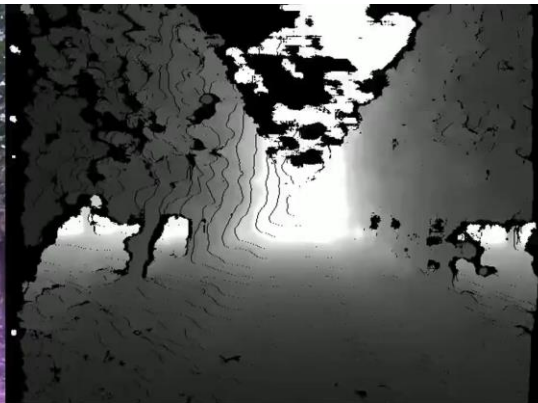
Optimized Model for Edge execution

- Inference: TFLite model at 60 fps
- Size: 4MB

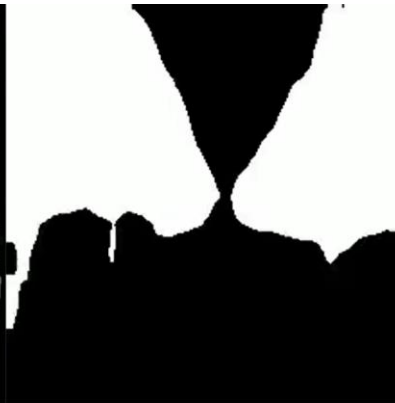
RGB



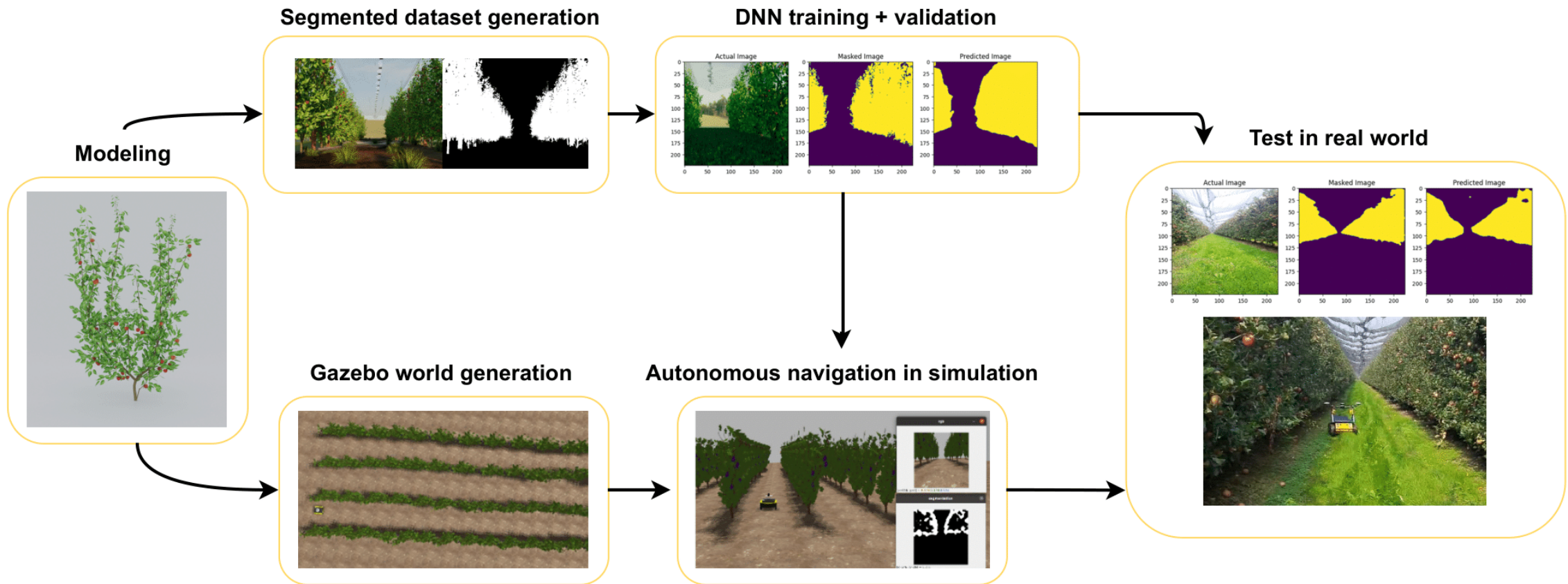
Depth



Mask



DNN are data hungry! Where do crops data come from?



Martini, M., Ambrosio, M., Navone, A., Tuberga, B., & Chiaberge, M. (2024). Enhancing visual autonomous navigation in row-based crops with effective synthetic data generation. *Precision Agriculture*, 1-22.

Contatti

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Cognitive and Human-Centered Robotics @CSL

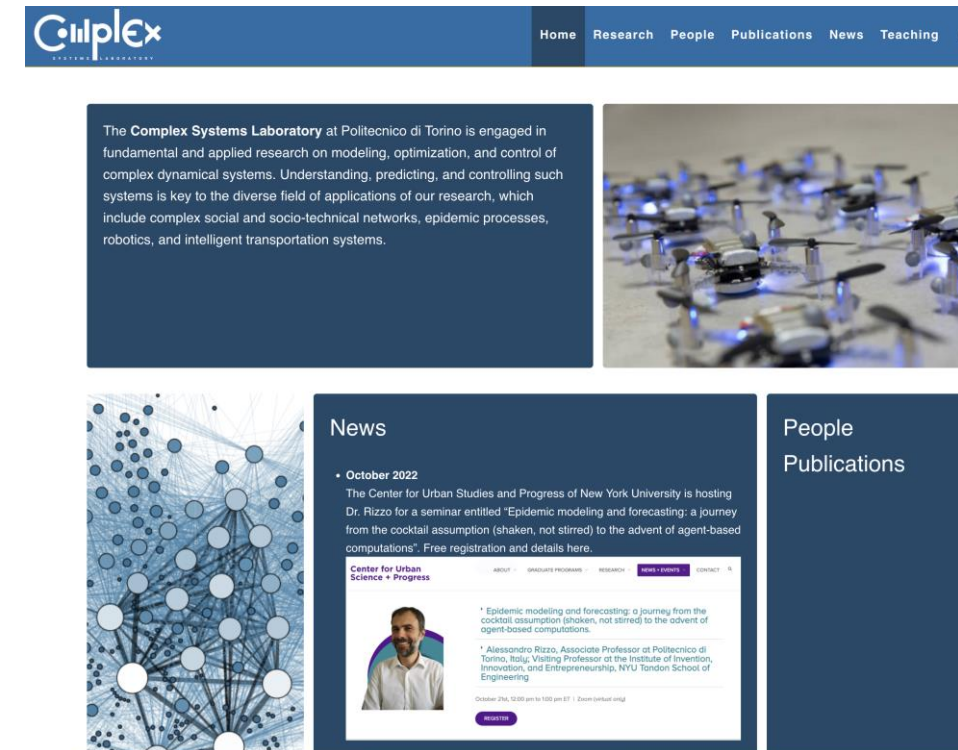
A. Rizzo, Complex Systems Laboratory



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Context and Skills @ csl.polito.it

- **Cognitive Robotics:** endowing a robot with intelligent behavior by providing it with a processing architecture that will allow it to learn and reason about how to behave in response to complex goals in a complex world
- **Human-centered robotics:** fostering the safe and efficient co-existence and cooperation of humans and robots
- **Tools:** adaptive and robust controls, intelligent navigation, interpretable and explainable AI, network theory and multi-agent control, game theory, bounded rationality, etc.

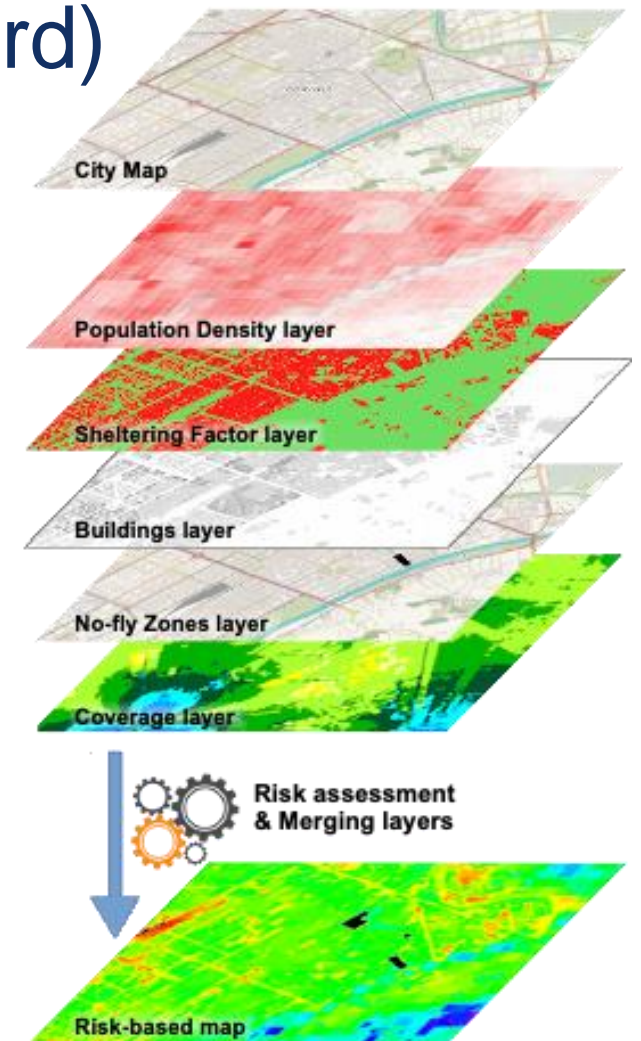


Application Portfolio

Risk-Aware navigation for UAS (joint with DIMEAS - Amazon Research Award)

Framework for safe BVLOS operations

- Urban Air Mobility
- Probabilistic Risk Assessment approach
- Layers: Population Density layer, Sheltering Factor layer, Buildings layer, No-fly zones layer, etc.
- Risk-aware path planning and replanning (riskA*, risk RRTX)



Management of mixed teams of manned and unmanned aerial vehicles (joint with DIMEAS - commercial research)

A team of one manned vehicle and many unmanned vehicles must execute a complex mission

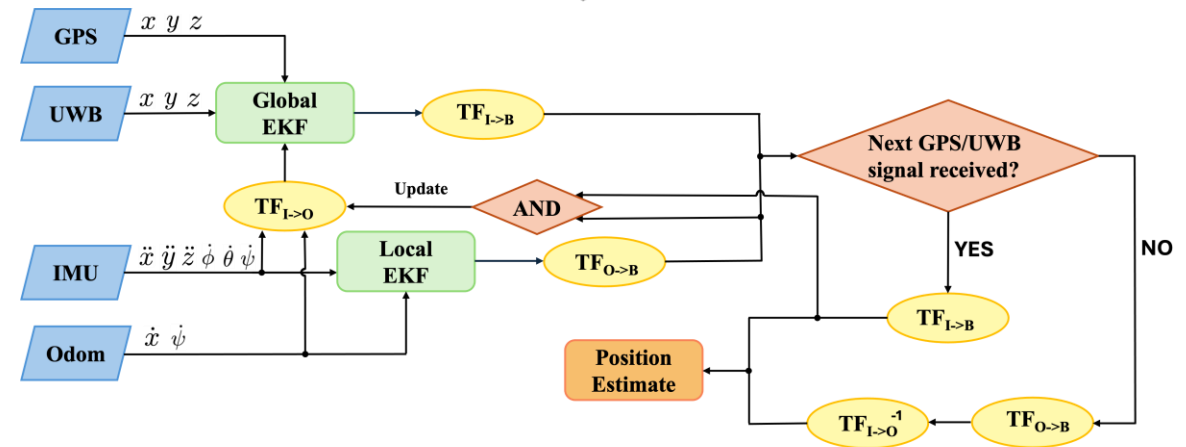
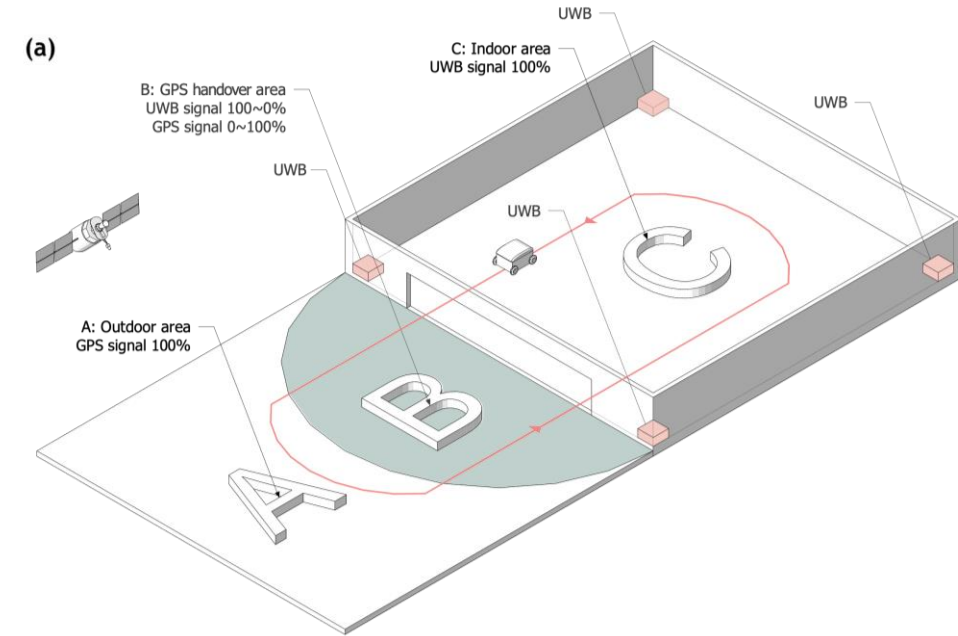
- The mission is planned on ground but can be perturbed during its execution
- Mission management accounts for the human pilot as a leader, considering their cognitive status
- Missions are planned accounting for different vehicles capability and priorities
- Path planning and trajectory planning are continuously updated on each aircraft
- Based on optimization - multi-agent control theory



Indoor-outdoor localization handover

Seamlessly manage and fuse different sensing sources with different accuracy toward accurate localization

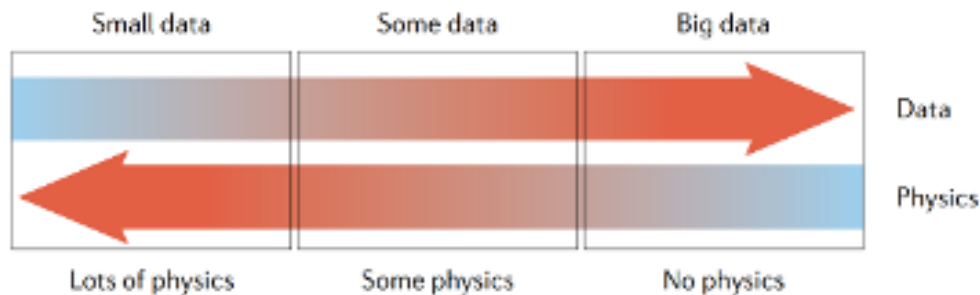
- Indoor: UWB, Odometry, IMU
- Outdoor: GPS, Odometry, IMU
- Presence of mixed zones
- Based on Kalman filters and sensor fusion



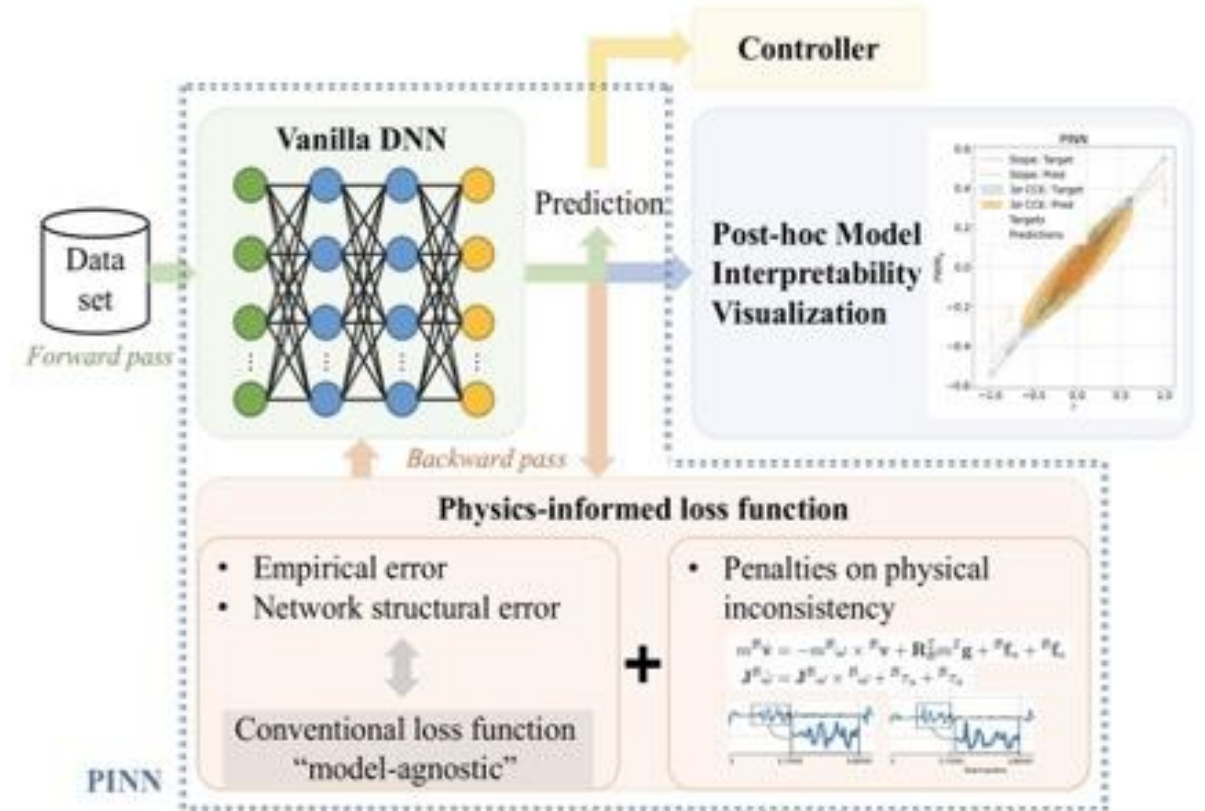
Physics-informed neural networks for modeling and control of complex robotic systems (Amazon Research Award)

A neural network framework that incorporates domain knowledge

- Learn with less
- Generalize far from training data
- Provide interpretability



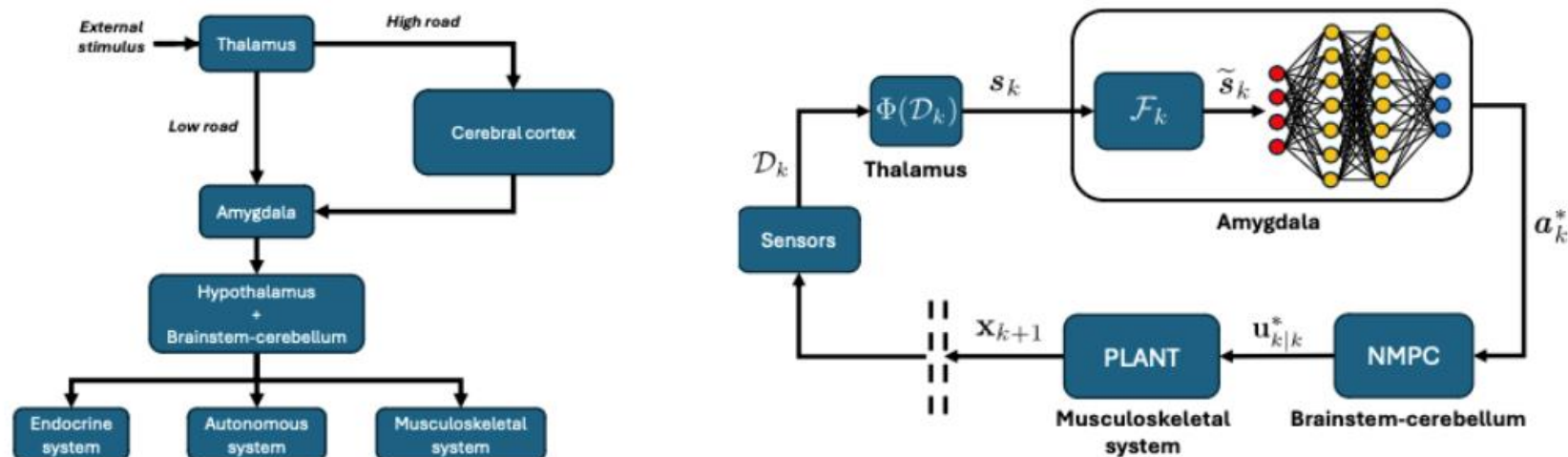
amazon | science



Incorporating artificial emotions to enhance self-preservation and social acceptance in robot navigation

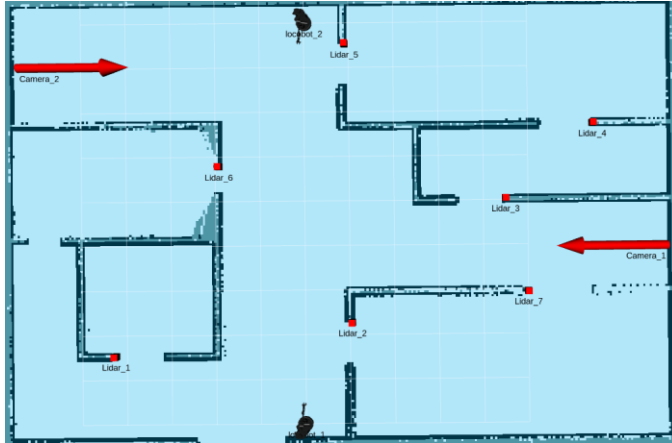
Emotions are pre-programmed reactions of animals to maintain homeostasis and self-preservation (fear, rage, disgust...)

- A euro-inspired control architecture to incorporate artificial fear in robots
- Resulting in an adaptive RL-NMPC with different levels of fear-induced response
- Implementing LeDoux “low-road paradigm”, working on the “high-road” at present (using Large Language Models)



Using LLMs to emulate high-level planning and the high-road of cognitive models

Prompts



The image I am providing represents a gridmap of an indoor environment with several open rooms with no doors. The pixelated areas in black represent the impassable walls of the room. The areas in light blue represent the actual walkable areas. At each room entrance there is a Lidar, numbered from 1 to 7 and indicated in the image by the red squares. The arrows represent security teleCameras and are numbered 1 to 2 in the image. At the top and bottom of the room there are two robots, indicated as "locobot_1" and "locobot_2" in the image.

Consider a surveillance application. I will provide a description of the scenario under consideration by giving you a list of sensors that have been activated sequentially. Your purpose is to analyze the scenario, determine what zone needs to be monitored, briefly explain the logic behind your motivation, and determine which robot makes the most sense to activate to go monitor the established zone. For the moment, try to identify which robot is closest to the targeted area and is therefore likely to take the least time to arrive and check.

Answers

Based on your provided map and description, if you give me the sequence of activated sensors, I will analyze the scenario and identify the zone that needs monitoring. I'll also determine which robot is closer to the zone and provide reasoning for the choice. Please share the sensor activation sequence to proceed.

Camera_1, Lidar_3, Lidar_4

Based on the activation sequence of **Camera_1**, **Lidar_3**, and **Lidar_4**, here's the analysis:

Analysis of the scenario:

1. **Camera_1 activation** suggests an event or movement has been detected in the area near the **right side of the map**, as its field of view aligns with that zone.
2. **Lidar_3 activation** indicates an object or movement near the **corridor to the right**, just below Camera_1's coverage area.
3. **Lidar_4 activation** further narrows down the target zone to the **room near the right side** since it is positioned in the nearby corridor.

Conclusion:

The zone requiring monitoring is the **rightmost room** (where **Lidar_4** is located). The progression of activations indicates that the activity is moving deeper into that room.

Robot selection:

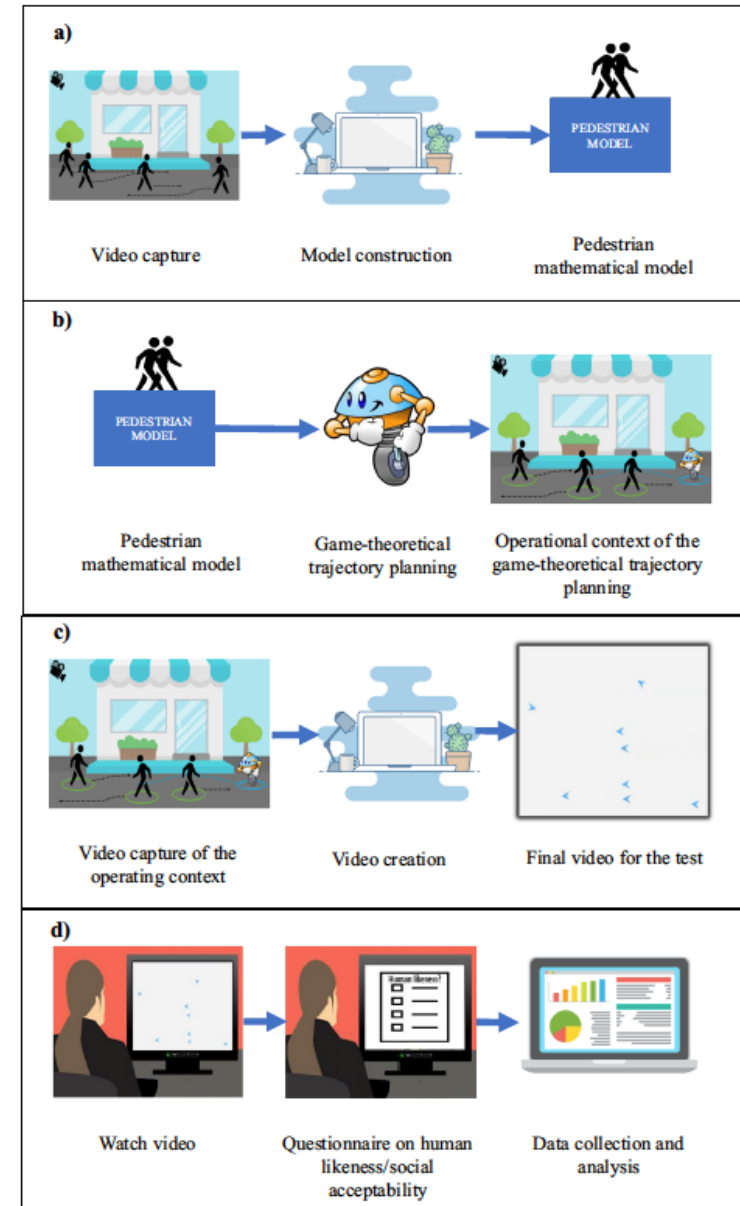
- **locobot_2** is closer to the target zone compared to **locobot_1**, which is at the bottom of the map.
- **Locobot_2** can move directly through the corridors near **Lidar_5** and **Lidar_3**, reducing response time.

Thus, **locobot_2** is the logical choice to monitor the area.

Socially-acceptable service robots

Increase trust and familiarity in human-robot interactions

- Modeling human behavior through a game-theoretical approach
- Endowing the robot with a human-like motion model
- Testing measurable performance and social acceptability



Contatti

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Autonomous Grape Harvesting: Design of Integrated Solutions for Efficient Robotic Harvesting

M. Vacca

M. Ruo Roch



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Contest and Motivations

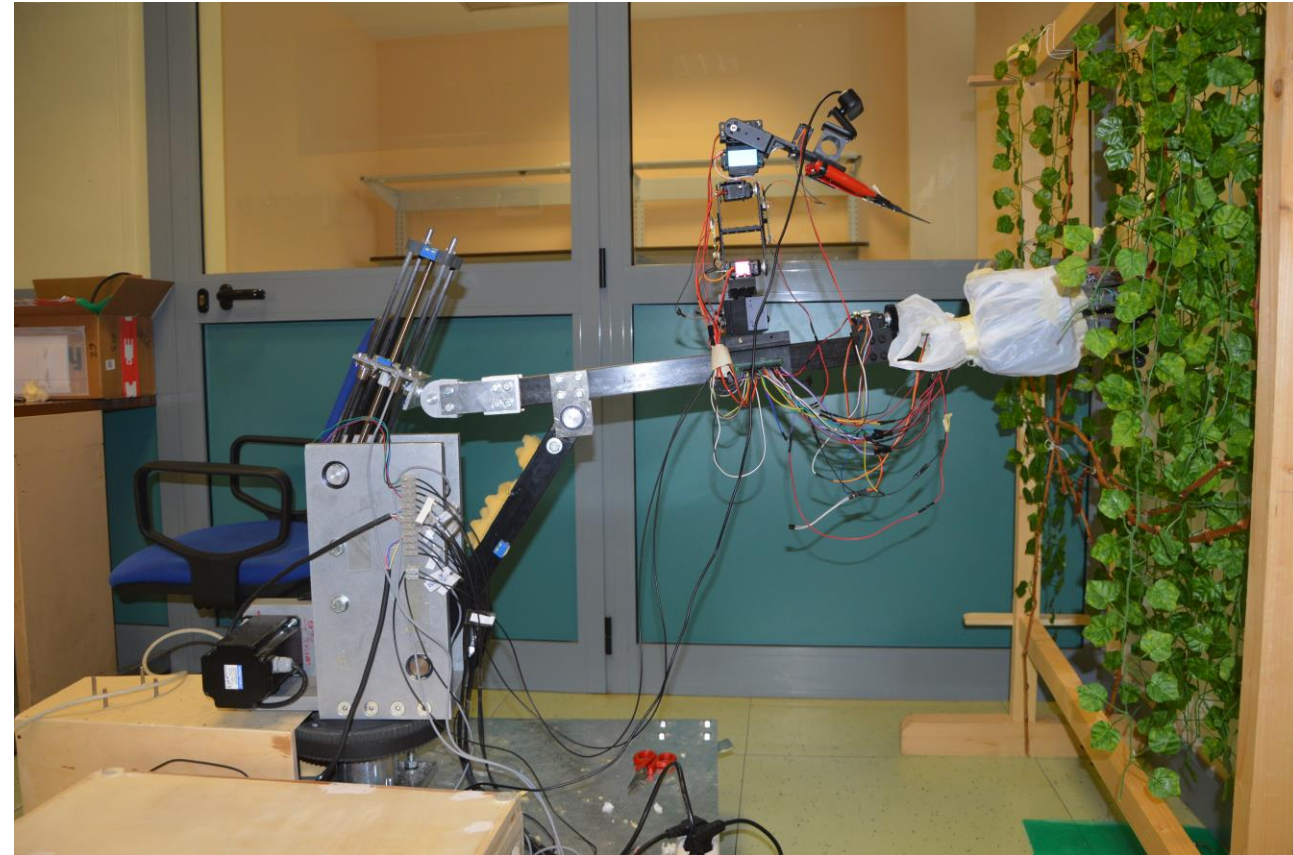
- **Grape harvesting is becoming increasingly difficult to accomplish**
 - Lack of manpower
 - Difficulties in hiring people



- **Mechanical (shaking) harvesters are only a partial solution**
 - Too big
 - They damage the fruit and the plant

Contest and Motivations

- The focus of our research activity is therefore **the development of an autonomous robotic arm for grape harvesting**
- Key points:
 - **Analyze the human harvesting process and apply key elements to the design** of an optimized robotic arm
 - **Study optimal solutions covering all aspects of the robot:** mechanical, electronic, and algorithmic

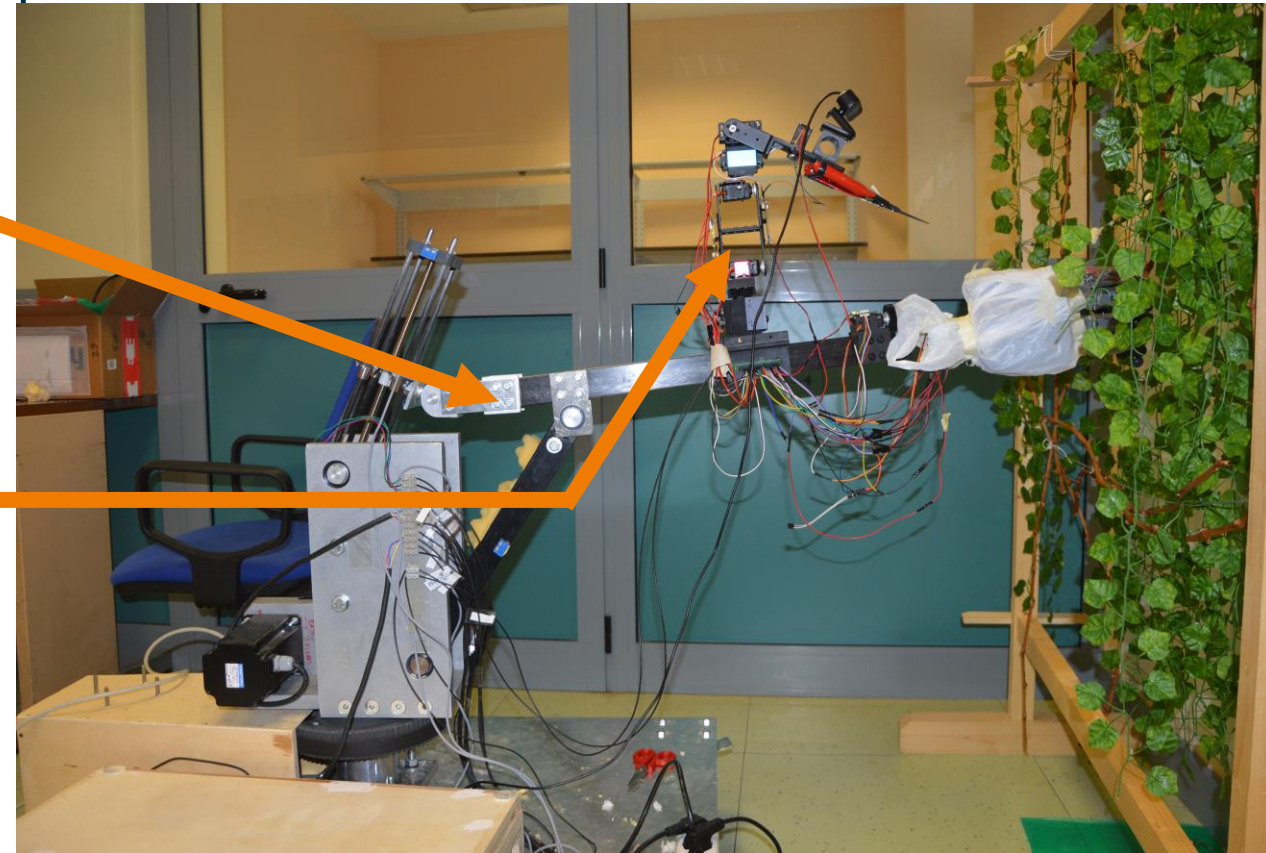


Developed solution 1: Robotic Arm(s)

- **To efficiently harvest bunches of grape** without damaging it **two arms are required**
 - One for grabbing and one for cutting
 - But the two arms have two different requirement

Developed solution 1: Robotic Arm(s)

- **To efficiently harvest bunches of grape** without damaging it **two arms are required**
 - One for grabbing and one for cutting
 - But the two arms have two different requirement
- **Developed solution**
 - One big arm to grab the bunch of grape
 - Large movement area
 - Payload > 2,5Kg
 - One small arm inserted at the elbow with the cutting tool and the camera
 - Small movement area (around the bunch of grape)
 - Low payload



Developed solutions 2: End Effector

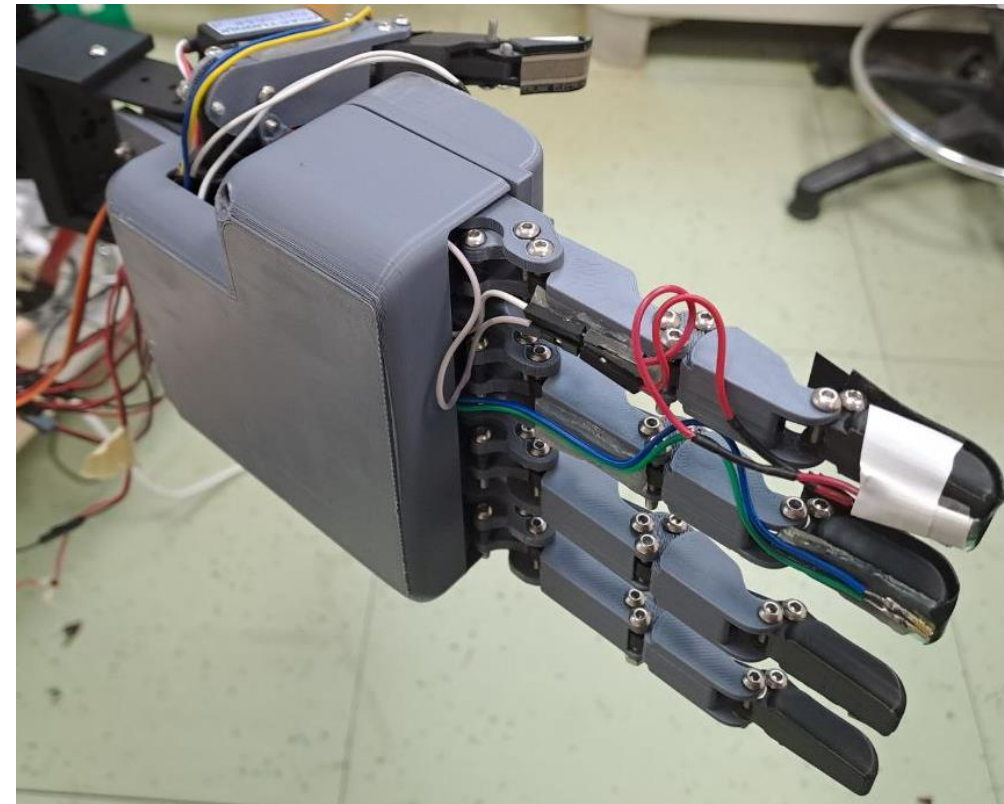
- Do we need a humanoid hand to harvest grapes?

Developed solutions 2: End Effector

- Do we need a humanoid hand to harvest grapes?
- **No, we just need some of the human hand characteristics...**
 - Variable section (to easily enter «inside» the vineyard)
 - Ability to adapt to the shape of a bunch of grape
- **...plus some additional requirements**
 - Simple and robust actuation (very very dirty environment)

Developed solutions 2: End Effector

- Do we need a humanoid hand to harvest grapes?
- **No, we just need some of the human hand characteristics...**
 - Variable section (to easily enter «inside» the vineyard)
 - Ability to adapt to the shape of a bunch of grape
- **...plus some additional requirements**
 - Simple and robust actuation (very very dirty environment)
- **Developed solution: start from an open source humanoid hand and modify it to:**
 - Improve the effectiveness of the grab gesture
 - Allow the insertion of electronics and sensors

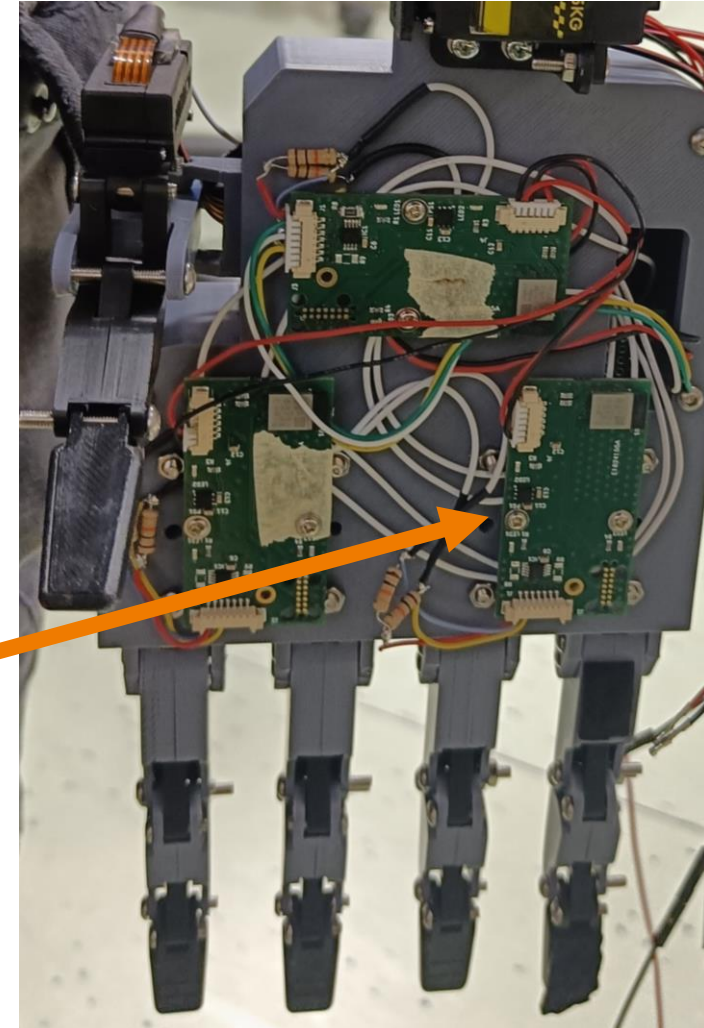


Developed solutions 3: Sense of Touch

- Like in human harvesting **the algorithm is based on sight and touch senses**
- **Touch plays a fundamental role** but is difficult to implement
 - Many sensors must be used of different types
 - How to place and connect them?

Developed solutions 3: Sense of Touch

- Like in human harvesting **the algorithm is based on sight and touch senses**
- **Touch plays a fundamental role** but is difficult to implement
 - Many sensors must be used of different types
 - How to place and connect them?
- **Developed solutions:**
 - Custom small footprint pcb with bluetooth controller
 - Innovative sensor acquisition systems that (theoretically) allows to connect thousands of sensors of different types with only local wiring required



Contatti

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Thank you for your attention!



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Soluzioni avanzate per la robotica industriale

M. Indri



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Contesto e competenze

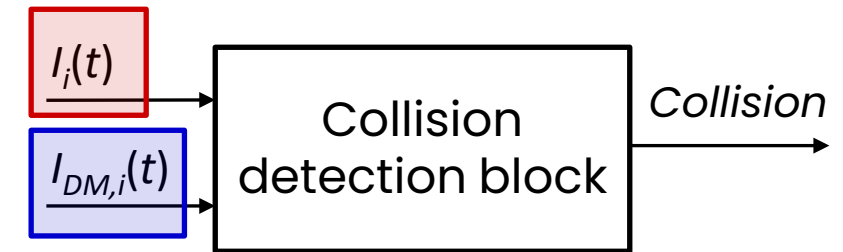
Contesto: sviluppo di soluzioni robotiche innovative per l'implementazione dei principi di Industria 4.0 in realtà industriali pre-esistenti in collaborazione con industrie (Comau, Efort)

Obiettivi: miglioramento delle prestazioni di robot industriali standard attraverso soluzioni software e di controllo, principalmente basate sui sensori disponibili

Metodologie e competenze: sviluppo di sensori virtuali per la rilevazione di collisioni, modellistica e identificazione dell'attrito statico e dinamico, implementazione di schemi di controllo H_∞ , pianificazione della traiettoria per sistemi ridondanti

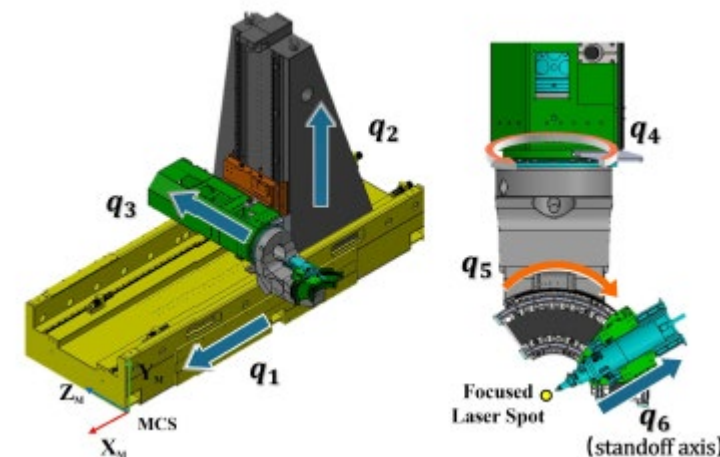
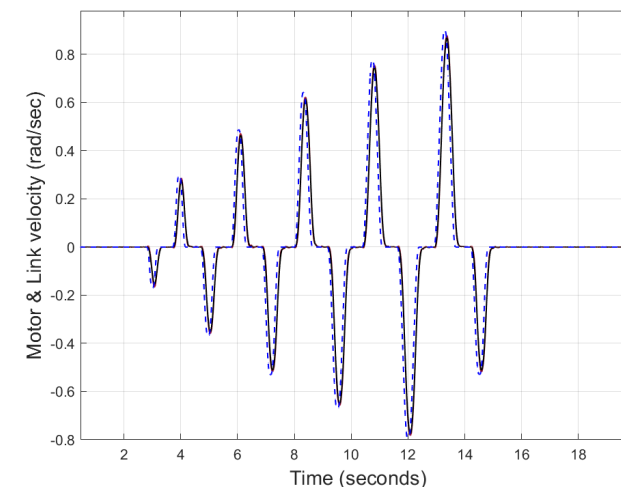
Soluzioni sviluppate / 1

- Sensore virtuale per la **rilevazione di collisioni** per robot non-collaborativi (con Comau)
 - Utilizza informazioni già disponibili per il controllo
 - Monitora correnti misurate e stimate e le loro derivate
 - Rileva collisioni usando una soglia variabile, che include una stima dell'errore di modello
- Framework per **l'identificazione dell'attrito** statico e dinamico per manipolatori industriali (con Comau – PhD in apprendistato)
 - Consente di utilizzare modelli di attrito di varia complessità
 - Permette di avere un modello dinamico del robot affidabile anche in condizioni critiche del moto (basse velocità)



Soluzioni sviluppate / 2

- Implementazione di uno schema di **controllo H_∞** nell'architettura industriale di controllo di un servomeccanismo (con Comau)
 - Permette di evitare oscillazioni del braccio grazie ad un'appropriata definizione delle funzioni di peso
- Ottimizzazione della **traiettoria** per **macchine** da taglio laser **3D ridondanti** (con Efort – PhD industriale)



Contatti

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Collaborazione uomo-machina per agenti e manipolatori

P. D. Cen Cheng, M. Indri



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di Torino**

Contesto e competenze

Contesto: Sviluppo di applicazioni robotiche per migliorare l'interazione uomo-robot nel contesto di Industria 5.0

Obiettivi:

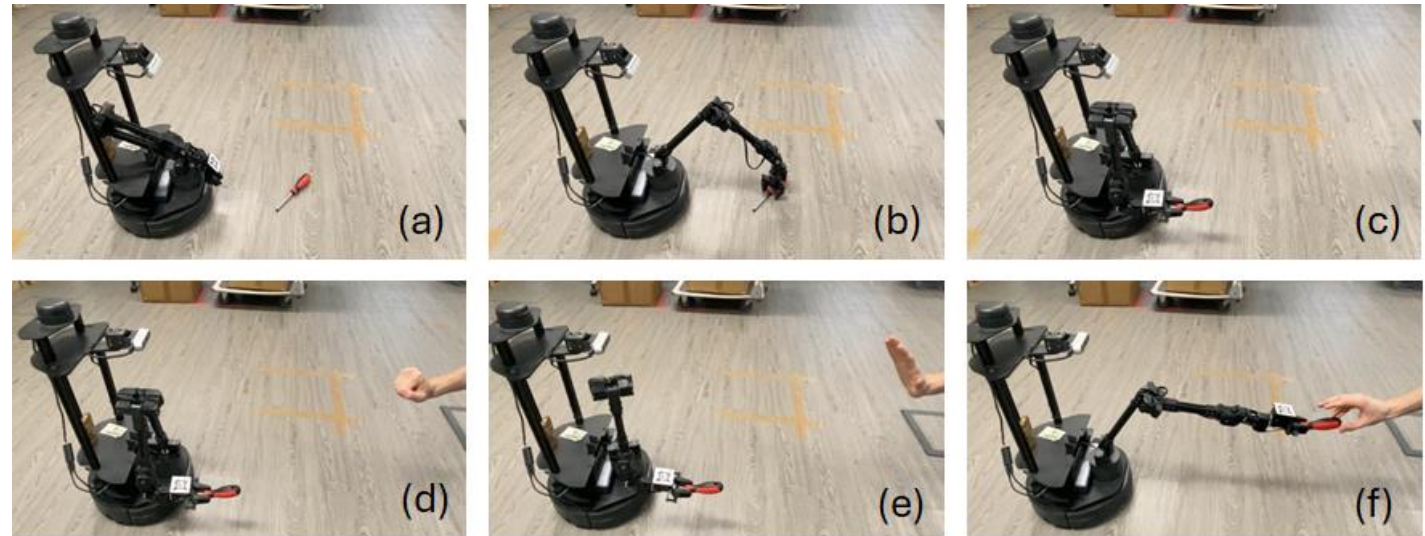
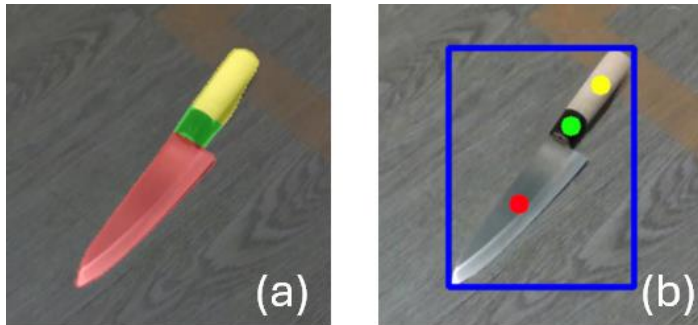
- Design di un framework sistema uomo-centrico: I robot operano insieme all'uomo in spazi di lavoro condivisi
- Adattamento di approcci complessi in sistemi low-resource
- Garantire la sicurezza verso l'uomo durante l'interazione uomo-robot

Competenze: Sviluppo di architetture software tramite l'utilizzo di tools open-source per manipolatori mobili

Soluzioni sviluppate / 1

Riconoscimento smart degli oggetti e identificazione delle pose di presa di tali oggetti:

- Identificazione di parti pericolose dell'oggetto da prendere
- Stima della posa di presa dell'oggetto
- Pianificazione dell'handover robot-umano



Soluzioni sviluppate / 2

Navigazione sicura in ambienti condivisi con altri agenti e persone

- Pianificazione della traiettoria tenendo conto degli umani come ostacoli dinamici «speciali»
 - Utile per creare un'area virtuale di sicurezza attorno alle persone mentre il robot si muove
 - Garantisce la sicurezza particolarmente quando il robot è ingombrante o trasporta oggetti pericolosi
- L'area virtuale occupata dall'umano è percepita dal robot come un ostacolo con una forma Gaussiana, proporzionale alla sua velocità

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