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XXXVI Cycle

Machine Learning for Autonomous Navigation in Service Robotics

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Research context and motivation

Service Robotics
A "service robot" is defined as a robot "that performs useful tasks for humans or equipment excluding industrial automation applications". Service robots are spreading as cutting-edge automation solutions in various fields where human activities can be supported.
Indoor social applications for wellbeing: service robots can support people in every-day life activities in their domestic environments. They can be adopted for smart home management, elderly people monitoring and assistance, surveillance and inspection.
Precision Agriculture: the development of Agriculture 4.0 paradigm rapidly attracted research attention with the aim of satisfying essential requirements: increasing productivity, allocating resources reasonably, adapting to climate change, and avoiding food waste. A fundamental step for introducing an efficient and reliable automation in the agriculture processes is the development of a robotic autonomous navigation pipeline. This is the first requirement to successfully takes care of several tasks such as harvesting, spraying, and vegetative assessment.

SERVICE ROBOTICS FOR WELLBEING

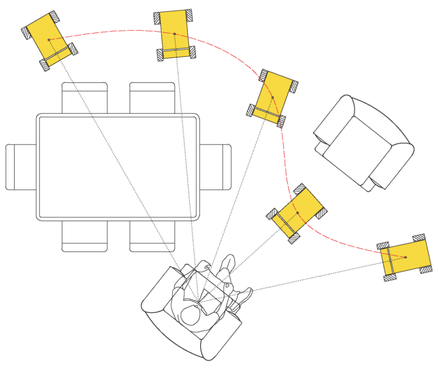
PRECISION AGRICULTURE

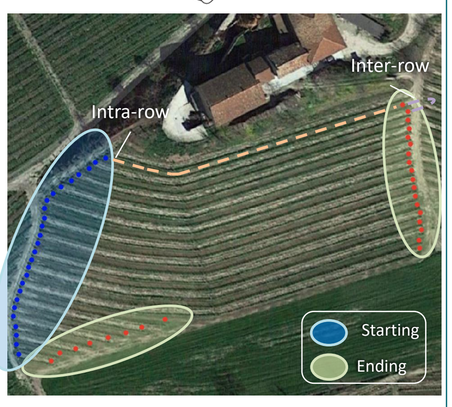
Addressed research questions/problems

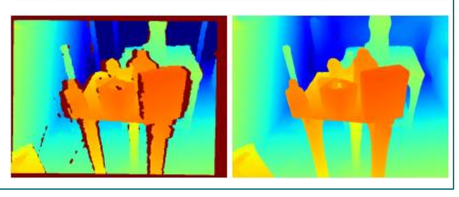
Indoor Autonomous Social Navigation:
- Increase the level of autonomy of robotic navigation in dynamic social environment.
- Investigate novel Machine Learning-based approaches for robot control and path planning.

Autonomous Navigation for precision agriculture:
- Propose a complete autonomous navigation pipeline for row-based crops such as vineyards: from a global waypoints generator to a local intra-row controller.
- Study position-independent visual sensorimotor agents for intra-row navigation in GPS-denied conditions.

Robotic Perception:
- Deep Learning at the Edge: study optimization methods for Deep Neural Networks execution with real-time performances on embedded devices.
- Applications to robotic tasks: person detection and pose estimation, scene semantic segmentation, image super-resolution, depth images noise estimation.
- Generalization to Out-Of-Distribution data: investigation of Deep Learning methods for domain-invariant models for visual perception and navigation.





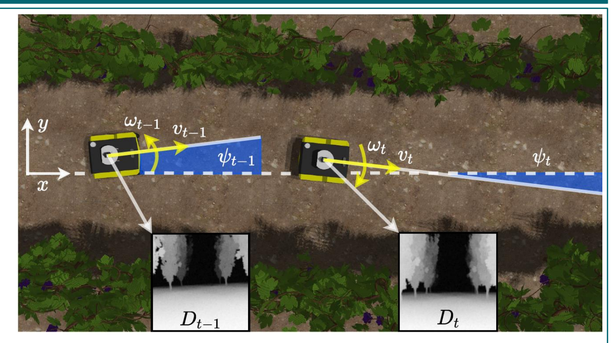


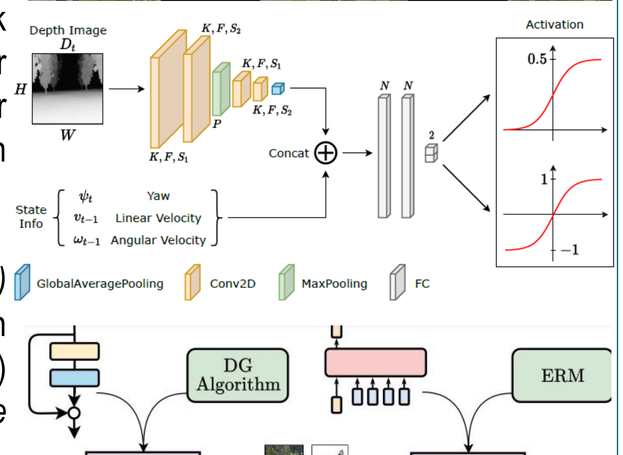
Novel contributions

- **Marvin**: an innovative **omni-directional robotic platform** for domestic environments. **human-centered navigation system** with omnidirectional robots for indoor assistance.
- A **position-agnostic autonomous navigation system** for intra-row **vineyards** with a visual-based **Deep Reinforcement Learning** agent.
- A **waypoint generator** with Deep Contrastive Clustering for row-based crops.
- **Land cover classification** from multi-temporal satellite images with adversarial training of a self-attention-based neural network.
- A deep investigation of recent **backbones architectures for Domain Generalization**.
- A **Generative Adversarial Super-Resolution network** for efficient image transmission at the Edge with Knowledge Distillation.

Adopted methodologies

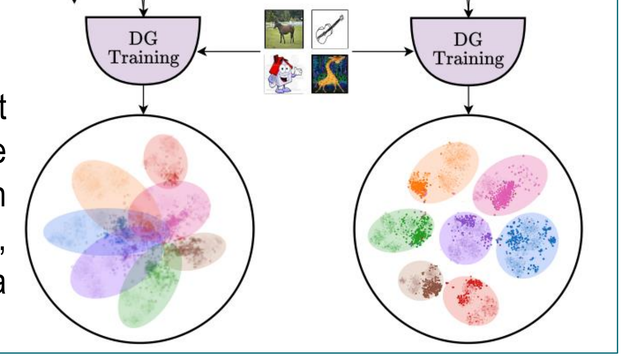
Deep Reinforcement Learning in simulation:
A reinforcement learning framework is formulated as a Markov Decision Process (MDP). The aim of a DRL process is to optimize a *parametric policy* π_θ which defines the agent behavior mapping the received state s_t to an action a_t. We define the parametrized agent policy with an Artificial Neural Network trained in simulation. DRL agents are used for both intra-row vineyards navigation and indoor social navigation. They can be combined with classic planners for a robust optimized system.





Edge-AI for robot perception:
The execution of *Deep Neural Networks (DNN)* for robotic perception is optimized through methods (*Knowledge Distillation, Quantization*) and dedicated computational hardware (*Google Coral accelerator*).

Domain Generalization:
Domain Generalization methods aim at minimizing the learning gap between source domains (simulation) to a target domain (reality). DNN architectures, training methods, and input sensor data are investigated for a domain-invariant visual-based navigation.



Future work

- Novel **RL-based hybrid planner**: adaptative social planners for service robotics tasks.
- Optimization techniques: **knowledge distillation** and **sparse neural networks**.
- **Realistic depth images in simulation**: bridge the gap in visual navigation policy.
- Machine Learning for **robot odometric error correction**.

Submitted and published works

- **Martini, M.**, Mazzia, V., Khaliq, A., & Chiaberge, M. (2021). Domain-adversarial training of self-attention-based networks for land cover classification using multi-temporal Sentinel-2 satellite imagery. Remote Sensing, 13(13), 2564.
- **Martini, Mauro**, Mazzia, Vittorio, Angarano, Simone, Gandini, Dario, & Chiaberge, Marcello. (2021, October 10). Local Planners with Deep Reinforcement Learning for Indoor Autonomous Navigation. https://doi.org/10.5281/zenodo.6367976
- **Martini, M.**, Cerrato, S., Salvetti, F., Angarano, S., & Chiaberge, M. (2022). Position-Agnostic Autonomous Navigation in Vineyards with Deep Reinforcement Learning. (Accepted at CASE 2022)
- Eirale, A., **Martini, M.**, Tagliavini, L., Gandini, D., Chiaberge, M., & Quaglia, G. (2022). Marvin: An Innovative Omni-Directional Robotic Assistant for Domestic Environments. Sensors, 22(14), 5261.
- Eirale, A., **Martini, M.**, & Chiaberge, M. (2022). Human-Centered Navigation and Person Following with Omnidirectional Robot for Indoor Assistance and Monitoring (Submitted to Robotics)
- Eirale, A., **Martini, M.**, & Chiaberge, M. (2022). RL-DWA Omnidirectional Motion Planning for Person Following in Domestic Assistance and Monitoring (Submitted to ICRA 2023)
- Angarano, S., **Martini, M.**, Salvetti, F., Mazzia, V., & Chiaberge, M. (2022). Back-to-Bones: Rediscovering the Role of Backbones in Domain Generalization. (Submitted to Pattern Recognition, Elsevier)
- Salvetti, F., Angarano, S., **Martini, M.**, Cerrato, S., & Chiaberge, M. (2022). Waypoint Generation in Row-based Crops with Deep Learning and Contrastive Clustering. (Accepted at ECML PKDD 2022)
- Angarano, S., Salvetti, F., **Martini, M.**, & Chiaberge, M. (2022). Generative Adversarial Super-Resolution at the Edge with Knowledge Distillation. (Submitted to Engineering Applications of Artificial Intelligence, Elsevier)

List of attended classes

- 01UMNRV – Advanced Deep Learning (didattica di eccellenza) (15/06/2021, 6 credits)
- 01UJBRV – Adversarial training of neural networks (03/06/2021, 3 credits)
- 01QTEIU – Data mining concepts and algorithms (01/02/2021, 4 credits)
- 01UJUIU – Human-AI Interaction (09/02/2022, 4 credits)
- 03QTIIU – Mimetic Learning (26/01/2021, 4 credits)
- 01DNMIU – Optimized execution of neural networks at the edge (05/09/2022, 5 credits)
- 01SCTIU – Text mining and analytics (30/09/2021, 3 credits)
- 01TSGKG – The Monte Carlo method (25/09/2021, 6 credits)
- 01QORRV – Writing Scientific Papers in English (20/5/2021, 3 credits)
- 01SHMRV – Entrepreneurial Finance (31/12/2020, 1 credit)
- 08IXTRV – Project management (18/01/2021, 1 credit)
- 01RISRV – Public Speaking (06/01/2022, 1 credit)
- 02LWHRV – Communication (28/12/2020, 1 credit)
- 01PJMRV – Etica informatica (07/05/2021, 4 credits)

PhD program in
Electrical, Electronics and Communications Engineering