Ph.D. in Information Technology
Thesis Defenses

March 12th, 2026
At 3:30 p.m.
Room BIO 1 - Building 21

Matteo COLOMBO – XXXVIII Cycle

INCREASING DEXTERITY OF ROBOTIC MANIPULATION TASKS IN UNSTRUCTURED INDUSTRIAL ENVIRONMENTS

Supervisor: Prof. Paolo Rocco

Abstract:

In the last decades, robotic arms have revolutionized the automation of industrial manufacturing processes, dramatically enhancing their productivity. Robots have been used in several applications, such as palletizing, welding, painting, and machine tending. Nevertheless, all these operations are usually carried out in well-known and organised workstations in a continuous and repetitive way. The robots are pre-programmed to follow a fixed set of instructions, which is repeated several times to complete the task at hand. This approach translates to a complete lack of dexterity and adaptability, and needs to be evolved in order to answer the new demands for flexible and quickly reconfigurable robotic systems brought forth by the latest industrial paradigm shifts. While the introduction of collaborative robots marked a significant step towards expanding automation capabilities, their effectiveness in dynamic and unstructured scenarios remains limited by insufficient dexterous skills, which are critical in tasks such as kitting, packaging, or random bin picking. These tasks are characterized by the presence of uncertainty when planning for object manipulation, which needs to be accounted for. Grasp poses are often random; different placement poses for the same object may be required during the same task, and the grasp target could be potentially occluded by other objects. Furthermore, as the robotic system should be flexible and readily reconfigurable, it should not excessively rely on external fixtures.

This thesis addresses the challenge of enhancing robotic manipulation dexterity in unstructured industrial environments using simple, industry-ready hardware such as parallel grippers. We propose a set of model-based and learning-based control strategies that enable flexible object reorientation, regrasping, and retrieval tasks without external fixtures or specialized multi-fingered hands. We start by focusing on the problem of arbitrarily reconfiguring an object from a random pose to a desired one. To address it, we first introduce a dual-arm manipulation planning framework that performs fixtureless object reorientation through optimized handover sequences. We leverage object data and gripper parameters to generate offline a compact regrasp graph and sets of feasible placement poses. The graph representation, combined with an online optimal handover planner, allows efficient planning and execution of long-horizon manipulation sequences, which are composed of a concatenated sequence of motion primitives.
Then, we present a multimodal approach that integrates vision and tactile feedback to plan and supervise in-hand object reorientation using a dual-arm robot, merging open-loop trajectory planning with tactile-based supervision. Vision-based data are used by a path planner to generate a feasible sliding path on grasped surface, along which the second arm can push the object held by the first one, in order to change its in-hand configuration without opening the gripper. This sliding motion is

supervised by a tactile classifier that learns from RGB and point cloud data if the current sliding motion is feasible. If it is not, the operation is halted and a replanning step is executed.
Finally, a deep reinforcement learning framework is proposed for object retrieval in cluttered environments, where complementary pushing and grasping policies are learned to coordinate exploration and target extraction in a push-to-grasp approach. This enables a robotic arm to manipulate the clutter in its workspace to reveal and grasp a target object. The push and grasp actions are generated by three deep neural networks, concurrently trained through a Deep Q-Network approach in simulated scenes. Two kinds of push actions are learned: find and retrieve. find is rewarded for revealing the object and for removing occlusions on top of it, while retrieve is rewarded for increasing the grasp score on the target, assigned by the grasp network after each executed push. Action selection is coordinated by a vision module that segments the scenes and generates a region of interest where the push actions are most likely to be effective once the object is revealed.

All methods have been validated in simulation and real-world experiments on collaborative robotic platforms to show their applicability in realistic scenarios.

Alessandra TAFURO – XXXVIII Cycle

AI-EMPOWERED ROBOTICS FOR MANUFACTURING AND WAREHOUSE ITEM HANDLING.
Supervisor: Prof. Paolo Rocco

This thesis explores the development of AI-powered robotic systems that transcend the traditional role of rigid, pre-programmed machines. It addresses the growing demand for intelligent and adaptive automation in modern industrial environments, which are increasingly defined by high variability and product customization. As manufacturing and logistics shift toward high-mix, low-volume production, conventional automation, reliant on precise models and fixed routines, has become progressively insufficient. In response, this research advances the field of intelligent robotics by integrating artificial intelligence, multi-modal sensing, and human-inspired cognitive capabilities, enabling robots to perceive, reason, and learn within complex and dynamic settings.
The pursuit of transforming robots into more autonomous agents is examined across three application domains: robotic surface polishing, deburring of deformable shoe soles, and object grasping in warehouse environments. Each scenario demands a high degree of perception, dexterity, and adaptability, qualities typically associated with human skill.
In manufacturing, a polishing path-planning algorithm is developed for free-form polysurfaces, allowing robots to perform finishing operations even when 3D models are unavailable. In the footwear industry, where rubber soles vary in shape, color, and material, two deburring setups are investigated: one with a fixed deburring tool and moving workpiece, and another with a fixed workpiece and moving tool. For the first configuration, a hybrid learning-from-demonstration framework is proposed, enabling robots to imitate expert actions through visual segmentation and motion modeling. This is further extended with a self-supervised vision-motion learning method that leverages reinforcement learning to associate visual inputs with tool trajectories, eliminating the need for labeled data or CAD models. For the second setup, a complete processing pipeline is developed, encompassing defect detection and execution, and incorporating online vision-based path correction to compensate for workpiece deformation. In the warehouse domain, a grasp learning framework is proposed that enables robots to acquire grasping strategies through experience and adapt them to novel yet similar objects.Overall, the proposed methodologies integrate AI, vision, and control to foster flexible and robust robotic behaviour, reducing dependence on expert programming while enhancing robotic autonomy.

PhD Committee

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