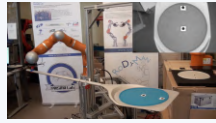


[DynLeg-1] – Robots that Push, Kick, Roll, and Balance: Dynamic Non-Prehensile Manipulation

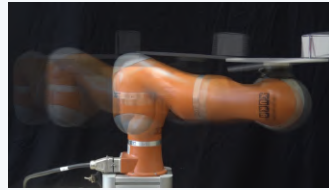
Thesis sheet · PRISMA Lab



Robot juggling



Robot baking a pizza



Object transported on a tray



Robot kicking a ball

THESIS OVERVIEW

This thesis explores how robots can manipulate objects without grasping them, reproducing dynamic skills such as pushing, rolling, kicking, and balancing objects. Non-prehensile manipulation refers to robotic manipulation strategies in which the object is not rigidly grasped, but is instead moved by exploiting unilateral contacts, friction, impacts, rolling, sliding, and the natural dynamics of the object. This class of tasks is particularly relevant because many human manipulation skills are not based on firm grasping only, but also on the ability to push, roll, slide, balance, throw, or catch objects. From a robotic perspective, these strategies may increase dexterity, enlarge the effective workspace, and allow robots to perform complex tasks even with simple end-effectors. At the same time, they introduce challenging modelling and control problems, due to underactuation, contact changes, hybrid dynamics, and the strong coupling between the robot motion and the object motion.

The thesis work will first focus on modelling and analysing the selected task in simulation environments. The system will then be controlled either to stabilise unstable equilibrium points, track prescribed paths, or execute higher-level planned tasks. Finally, the approach will be experimentally implemented using the robots and setups already available at PRISMA Lab.

TOOLS

Simulation & Middleware: ROS2 (Humble), Gazebo GZ, MuJoCo, Matlab/Simulink, NVIDIA ISAAC

Languages & Libraries: Python, C++, Matlab

Other: GitHub, Docker

SUPERVISOR

Prof. Fabio Ruggiero – fabio.ruggiero@unina.it

TECHNICAL SUPERVISOR

Dr. Mario Selvaggio – mario.selvaggio@unina.it

Dr. Pierluigi Arpentì – pierluigi.arpentì@unina.it

KEYWORDS

Non-prehensile manipulation; contact-rich manipulation; dexterous manipulation; juggling tasks.

EXAMPLES / POSSIBLE ACTIVITIES

• Track 1 – Object pushing

The robot pushes objects on a planar surface, exploiting contact forces and friction to move them toward desired positions or along prescribed paths.

• Track 2 – Rolling manipulation of a sphere on another sphere

The task consists of controlling the orientation and motion of a sphere rolling on another spherical or curved surface, highlighting the role of nonholonomic constraints and contact dynamics.

• Track 3 – Robotic kicking task

The robot performs an impulsive dynamic action, such as kicking an object, where the final motion depends on impact timing, contact location, and the exchanged momentum.

• Track 4 – Object transportation on a tray

The robot transports an object placed on a tray without grasping it, controlling accelerations and tray orientation to avoid slipping or falling while following a desired trajectory.

PREREQUISITES / NOTES

Recommended courses: Foundation of Robotics, Robotics Lab, Advanced Robotics.

Recommended skills: Python/C++, basic linear algebra, familiarity with ROS2.

Target degree: Master's in Automation and Robotics Engineering.

Note: The final thesis will focus on one selected track, or possibly another track discussed with the supervisor; hardware validation is strongly encouraged.

RELATED BIBLIOGRAPHY

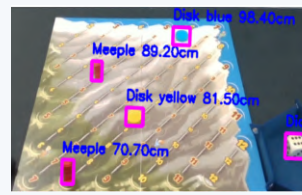
- F. Ruggiero, V. Lippiello, B. Siciliano, Nonprehensile dynamic manipulation: A survey, IEEE Robotics and Automation Letters, vol. 3, n. 3, pp. 1711-1718, 2018, DOI: 10.1109/LRA.2018.2801939.
- F. Ruggiero, A. Petit, D. Serra, A.C. Satici, J. Cacace, A. Donaire, F. Ficuciello, L.R. Buonocore, G.A. Fontanelli, V. Lippiello, L. Villani, B. Siciliano, Nonprehensile manipulation of deformable objects: Achievements and perspectives from the RoDyMan project, IEEE Robotics & Automation Magazine, vol. 25, pp. 83-92, 2018, DOI: 10.1109/MRA.2017.2781306.



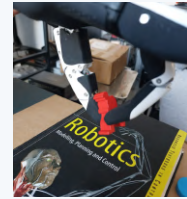
Robot playing a board game



Robot holding a dice



Object detection system



Robot grasping a meeple

THESIS OVERVIEW

The objective of this thesis is to develop algorithms and control techniques enabling a humanoid robot to play simple physical board games with one or more human users, either as a competitor, a teammate, or a supportive game companion. The activity is motivated by the growing interest in assistive and companion robots for elderly people, people living alone, and users who may benefit from engaging, cognitively stimulating, and socially meaningful interactions in everyday environments.

Unlike purely digital games, physical board games require the robot to interact with real objects and with a shared game space. The robot will therefore need to perceive the board state through computer vision, understand the rules of the game, reason about possible moves, and physically manipulate game elements such as tokens, dice, cards, or small objects. Depending on the selected game, the robot may also need to grasp, place, move, or throw objects while maintaining a natural and safe interaction with the human players.

The thesis will address the integration of perception, manipulation, motion planning, and rule-based or AI-based reasoning to allow the robot to autonomously participate in the game. Beyond entertainment, the final system may become a first step toward robotic companions supporting recreational activities, cognitive training, motor exercises, and social engagement for elderly or isolated users.

TOOLS

Simulation & Middleware: ROS2 (Humble), DDS, MuJoCo, Matlab/Simulink

Languages & Libraries: Python, C++, OpenCV, Gym

Other: GitHub, Docker

Robot: H1-2

SUPERVISOR

Prof. Fabio Ruggiero - fabio.ruggiero@unina.it

TECHNICAL SUPERVISOR

Eng. Michele Avagnale – michele.avagnale@unina.it

Eng. Riccardo Aliotta – riccardo.aliotta@unina.it

KEYWORDS

Reinforcement learning, humanoid robots, human-robot interaction, computer vision.

EXAMPLES / POSSIBLE ACTIVITIES

• Track 1 – Adaptive Strategy via Machine Learning

Implement reinforcement learning techniques that allow the robot to dynamically adjust its gameplay strategy and difficulty level based on the human opponent's observed skill over time.

• Track 2 – Dexterous Manipulation

Focus on hand control and tactile sensing, enabling the robot to accurately pick up, hold, and handle physical game elements.

• Track 3 – Perception

Focus on the perception side: implement visual techniques, also based on artificial intelligence, to detect the environment, understand the context, recognize objects, etc.

PREREQUISITES / NOTES

Recommended courses: Artificial Intelligence, Foundation of Robotics, Robotics Lab, Robot Interaction Control.

Recommended skills: Python/C++, familiarity with ROS/ROS2, familiarity with OpenCV, Gym

Target degree: Suitable for different Master's programmes depending on the selected track.

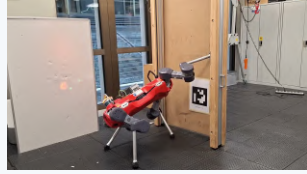
RELATED BIBLIOGRAPHY

[DynLeg-3] – Quadrupeds that Push and Pull: Legged Robots for Payload Transport

Thesis sheet · PRISMA Lab



ANYmal D and a box to push



ANYmal D and a door to open



Quadruped pulling a wheeled trailer



Quadrupeds pulling a box

THESIS OVERVIEW

Legged robots are increasingly expected to move objects, pull loads, and assist humans in environments where wheels or fixed manipulators are not effective. This research area focuses on the physical interaction between a quadruped robot and movable objects in the environment, possibly connected to the robot through a tether or a rigid link, to complete non-prehensile manipulation tasks, such as moving an object to a goal pose or carrying a payload.

Topics include vision integration for contact operations, payload-aware path planning, and robust locomotion in the presence of payloads.

Control methods leverage passivity-based approaches, graph theory, optimization techniques, and data-driven approaches.

The work includes simulation (Gazebo/ROS, NVIDIA Isaac) and experimental validation on PRISMA Lab platforms such as ANYmal D.

TOOLS

Simulation & Middleware: ROS (Noetic)/ROS2 (Humble), Gazebo, NVIDIA Isaac, Matlab/Simulink

Languages & Libraries: Python, C++, OpenCV (for vision-based tracks)

Other: GitHub, Docker

Robot: ANYmal D

SUPERVISOR

Prof. Fabio Ruggiero - fabio.ruggiero@unina.it

TECHNICAL SUPERVISOR

Eng. Federico Esposito – federico.esposito3@unina.it

KEYWORDS

Non-prehensile manipulation; legged robotics; planning.

EXAMPLES / POSSIBLE ACTIVITIES

• Track 1 – Pedipulation of Objects with a Quadruped Robot's Legs

Develop robust pushing algorithms for a quadruped robot, employing one or more of the legs to push the object. Modelling in Matlab or NVIDIA Isaac, testing in Gazebo on NVIDIA Isaac, implementation on ANYmal D.

• Track 2 – Tethered Payload Carrying

Develop robust planning and locomotion algorithms for a quadruped robot. Modelling in Matlab or NVIDIA Isaac, testing in Gazebo or NVIDIA Isaac, implementation on ANYmal D.

PREREQUISITES / NOTES

Recommended courses: Field and Service Robotics, Robot Interaction Control, Robotics Lab.

Recommended skills: Python/C++, familiarity with ROS/ROS2, familiarity with NVIDIA Isaac.

Target degree: Master's in Automation and Robotics Engineering.

Note: Track 1 requires acquiring some knowledge of computer vision (OpenCV).

RELATED BIBLIOGRAPHY

- ROS Documentation – <https://docs.ros.org/>
- Gazebo Simulator – <https://gazebo.org/>
- NVIDIA Isaac – <https://developer.nvidia.com/isaac/lab>
- Stolle, Jonas, et al. "Perceptive pedipulation with local obstacle avoidance." *2024 IEEE-RAS 23rd International Conference on Humanoid Robots (Humanoids)*. IEEE, 2024.
- Yang, Chenyu, et al. "Collaborative navigation and manipulation of a cable-towed load by multiple quadrupedal robots." *IEEE Robotics and Automation Letters* 7.4 (2022): 10041-10048.

[DynLeg-4] – From Parkour to Guide-Dog Locomotion: Task-Oriented Legged Robotics

Thesis sheet · PRISMA Lab



ANYmal D crossing a large gap



H1 performing a backflip



Quadruped acting as a guide dog



ANYmal D climbing a ladder

THESIS OVERVIEW

This research area focuses on the locomotion of a legged robot, with the goal of performing complex movements or of optimizing specific objectives. These capabilities are relevant for inspection, emergency response, assistance, and guide-robot applications, where the robot must adapt its motion to the task and to the human user.

Topics include robust and agile locomotion.

Control methods leverage optimization techniques and data-driven approaches.

The work includes simulation (Gazebo/ROS, NVIDIA Isaac) and experimental validation on PRISMA Lab platforms such as ANYmal D and H1-2.

TOOLS

Simulation & Middleware: ROS (Noetic)/ROS2 (Humble), Gazebo, MuJoCo, Nvidia Isaac, Matlab/Simulink

Languages & Libraries: Python, C++

Other: GitHub, Docker

Robot: ANYmal D, H1-2

SUPERVISOR

Prof. Fabio Ruggiero - fabio.ruggiero@unina.it

TECHNICAL SUPERVISOR

Eng. Federico Esposito – federico.esposito3@unina.it

KEYWORDS

Legged robotics; dynamic locomotion.

EXAMPLES / POSSIBLE ACTIVITIES

• Track 1 – Athletic Movement

Develop robust locomotion algorithms for a legged robot, maximizing the speed, performing jumps, increasing the weight that the robot can carry on its torso. Modelling in Matlab or NVIDIA Isaac, testing in Gazebo on NVIDIA Isaac, implementation on ANYmal D or H1-2.

• Track 2 – Quiet and Information-Rich Locomotion for Visually Impaired People

Develop locomotion algorithms to help a quadruped robot guide visually impaired people by minimizing the footstep noise and allowing the control of the planar velocity and the torso movement at the same time, in order to convey terrain slopes to the users. Modelling in Matlab or NVIDIA Isaac, testing in Gazebo on NVIDIA Isaac, implementation on ANYmal D.

PREREQUISITES / NOTES

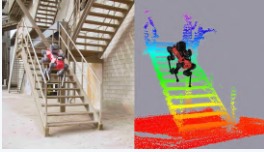
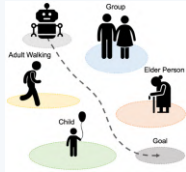

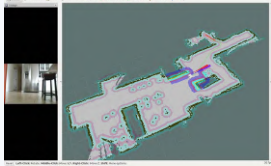
Recommended courses: Field and Service Robotics, Robot Interaction Control, Robotics Lab.

Recommended skills: Python/C++, familiarity with ROS/ROS2, familiarity with NVIDIA Isaac.

Target degree: Master's in Automation and Robotics Engineering.

RELATED BIBLIOGRAPHY

- ROS Documentation – <https://docs.ros.org/>
- Gazebo Simulator – <https://gazebo.org/>
- NVIDIA Isaac – <https://developer.nvidia.com/isaac/lab>
- Rudin, Nikita, et al. "Parkour in the wild: Learning a general and extensible agile locomotion policy using multi-expert distillation and RL fine-tuning." *arXiv preprint arXiv:2505.11164* (2025).
- Yu, Shangqun, et al. "Human-Centered Development of Guide Dog Robots: Quiet and Stable Locomotion Control." *arXiv preprint arXiv:2505.11808* (2025).

			
<p>Local map created by ANYmal D</p>	<p>Social navigation</p>	<p>Quadruped describing what it sees</p>	<p>Global map for autonomous navigation</p>

THESIS OVERVIEW

This research area focuses on equipping mobile robots with intelligent navigation and communication capabilities, allowing them to autonomously plan an optimal trajectory to a given goal and to communicate using natural language.

Topics include path planning, obstacle avoidance, vision, and natural language communication. Such capabilities are essential for robots that must operate in human environments, explain what they perceive, and navigate safely among people and obstacles.

Control methods leverage optimization techniques and data-driven approaches.

The work includes simulation (Gazebo/ROS, NVIDIA Isaac) and experimental validation on PRISMA Lab platforms.

TOOLS

Simulation & Middleware: ROS (Noetic)/ROS2 (Humble), Gazebo, NVIDIA Isaac, Matlab/Simulink

Languages & Libraries: Python, C++, OpenCV (for vision-based tracks)

Other: GitHub, Docker

Robot: ANYmal D, humanoid H1-2, rover.

SUPERVISOR

Prof. Fabio Ruggiero - fabio.ruggiero@unina.it

TECHNICAL SUPERVISOR

Eng. Federico Esposito – federico.esposito3@unina.it

KEYWORDS

Planning; social navigation; natural language.

EXAMPLES / POSSIBLE ACTIVITIES

• Track 1 – Multi-Sensor SLAM

Develop SLAM algorithms for a mobile robot, fusing the sensors available on the robot or installing new sensors for increased precision. Testing in Gazebo, implementation on PRISMA Lab platforms.

• Track 2 – Natural Language Communication

Develop algorithms to allow the robot to understand natural language and provide replies, using the robot's sensors to generate answers about the robot's environment. Testing in Gazebo on NVIDIA Isaac, implementation on PRISMA Lab platforms.

PREREQUISITES / NOTES

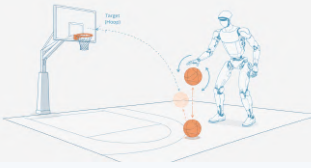
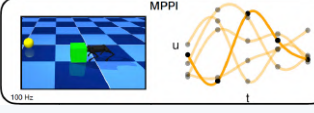
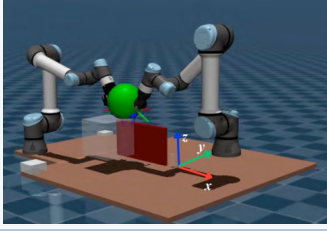
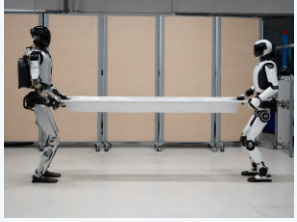
Recommended courses: Field and Service Robotics, Robot Interaction Control, Robotics Lab, Planning and Navigation, Artificial Intelligence, Mobile Robots, any course on perception.

Recommended skills: Python/C++, familiarity with ROS/ROS2.

Target degree: Suitable for different Master's programmes depending on the selected track.

RELATED BIBLIOGRAPHY

- ROS Documentation – <https://docs.ros.org/>
- Gazebo Simulator – <https://gazebo.org/>
- RTAB-Map – <https://github.com/introlab/rtabmap>
- Kwon, Jinse, Jemin Lee, and Yongin Kwon. "Design Practices and Lessons from Deploying On-device Vision-Language Interaction in Robotic Guide Dogs." *Proceedings of the IEEE/CVF International Conference on Computer Vision*. 2025.

			
<p>Basketball dribbling</p>	<p>Contact-rich pushing</p>	<p>Cooperative Manipulation</p>	<p>Cooperative Loco-Manipulation</p>

THESIS OVERVIEW

Sports-inspired and cooperative tasks provide challenging benchmarks for contact-rich loco-manipulation, where robots must combine fast reactions, physical interaction, and robust decision making. The thesis will investigate how hybrid control approaches combining learning-based methods and stochastic control can enable complex loco-manipulation tasks in challenging environments. The student will select one of the proposed research tracks and formulate the corresponding robotic problem within a suitable mathematical and computational framework. The activity will include validation in realistic robotic simulation environments and, where feasible, experimental testing on the lab's robotic platforms. The proposed methods will first be evaluated in dynamic simulators and, once their effectiveness has been validated, tested on real legged robotic platforms.

TOOLS

Simulation & Middleware: ROS2 (Humble), Gazebo GZ, MuJoCo, Matlab/Simulink

Languages & Libraries: Python, C++, Matlab

Other: GitHub, Docker

SUPERVISOR

Prof. Fabio Ruggiero – fabio.ruggiero@unina.it

TECHNICAL SUPERVISOR

Dr. Pierluigi Arpentì - pierluigi.arpenti@unina.it

KEYWORDS

Legged robotics; locomotion; manipulation; learning; stochastic control; hybrid algorithms.

EXAMPLES / POSSIBLE ACTIVITIES

Track 1 – RL-Guided MPPI for Robotic Basketball Dribbling

Development of a hybrid learning-based/stochastic-control framework for robotic basketball dribbling. Reinforcement learning will be used to learn a nominal hand–ball coordination strategy, while MPPI will refine the control action online to regulate the bouncing motion, maintain stable ball contact, compensate for rebound uncertainty, and recover from external disturbances or inaccurate ball trajectories.

Track 2 – RL-Guided MPPI for Robotic Soccer Dribbling

Development of a hybrid learning-based/stochastic-control framework for robotic soccer dribbling. Reinforcement learning will be used to learn a nominal foot–ball coordination strategy, while MPPI will refine the control action online to regulate ball motion, maintain stable possession, compensate for contact uncertainty, and recover from external disturbances or inaccurate ball trajectories.

Track 3 – RL-Guided MPPI for Cooperative Manipulation and Loco-Manipulation

Development of a hybrid learning-based/stochastic-control framework for cooperative manipulation between robotic agents. A learned policy will generate nominal leader behavior for coordinated object interaction, while MPPI will adapt the follower motion online to regulate interaction forces, compensate for object pose uncertainty, and maintain coordination during lifting and transportation tasks. The framework may be validated either with two robotic manipulators or with a pair of legged robots, extending the study toward cooperative loco-manipulation scenarios.

Track 4 – RL-Guided MPPI for Contact-Rich Object Pushing

Development of a hybrid learning-based/stochastic-control framework for contact-rich object pushing with a legged robot. A learned policy will generate nominal pushing behavior, while MPPI will refine the control action online to regulate contact interaction, compensate for friction changes and object pose uncertainty, and recover from unexpected deviations from the desired path.

Track 5 – RL-Guided MPPI for Quadruped Navigation on Unstable Terrain

Development of a hybrid learning-based/stochastic-control framework for quadruped navigation on irregular, unstable, and yielding terrains. Reinforcement learning will be used to learn nominal locomotion behaviors robust to terrain variability, while MPPI will refine the control action online to compensate for foot slippage, terrain deformation, uncertain ground reaction forces, and deviations from the desired path.

PREREQUISITES / NOTES

Recommended courses: Foundation of Robotics, Robotics Lab, Field and Service Robotics, Nonlinear Dynamics and Control.

Recommended skills: Python/C++, basic linear algebra, familiarity with ROS2.

Target degree: Master's in Automation and Robotics Engineering.

Note: The final thesis will focus on one selected track, or possibly another track discussed with the supervisor; hardware validation is strongly encouraged.


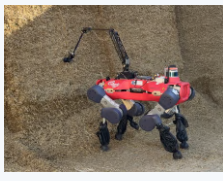


RELATED BIBLIOGRAPHY

- J. Alvarez-Padilla, J. Z. Zhang, S. Kwok, J. M. Dolan, and Z. Manchester, "Real-Time Whole-Body Control of Legged Robots with Model-Predictive Path Integral Control," in *Proc. IEEE International Conference on Robotics and Automation (ICRA)*, 2025, pp. 14721–14727.
- Y. Wu, H. Wang, R. Liu, and K. Hashimoto, "Adaptive Model Predictive Path Integral Control for Path Tracking of Legged Robots," in *Proc. 5th International Conference on Advanced Algorithms and Neural Networks (AANN)*, 2025, pp. 571–576. doi: 10.1109/AANN66429.2025.11257687.
- H. Keshavarz, A. Ramirez-Serrano, and M. Khadiv, "Control of Legged Robots Using Model Predictive Optimized Path Integral," in *Proc. IEEE-RAS International Conference on Humanoid Robots (Humanoids)*, 2025, pp. 1171–1178. doi: 10.1109/Humanoids65713.2025.11203053

[DynLeg-7] – Robots in the Field: Mobile Manipulation for Agrifood and Industrial Tasks

Thesis sheet · PRISMA Lab



			
<p><i>ANYmal D interacting with a vine</i></p>	<p><i>ANYmal D interacting with silage</i></p>	<p><i>ANYmal D uprooting grass</i></p>	<p><i>Spot opening a door</i></p>
<h3>THESIS OVERVIEW</h3> <p>Mobile manipulators can extend robotic autonomy to field, agrifood, and industrial scenarios where the robot must move through the environment and physically interact with objects, plants, tools, or structures.</p> <p>This research area focuses on the physical interaction between a mobile manipulator robot and mission-critical objects in the environment, to complete contact-rich manipulation tasks such as weed uprooting, object displacement, and interaction with agricultural or industrial materials.</p> <p>Topics include vision and force interaction control, collision-aware planning, whole-body robot control, robust locomotion with dynamic configurations.</p> <p>Control methods leverage passivity-based approaches, graph theory, optimization techniques, and data-driven approaches.</p> <p>The work includes simulation (Gazebo/ROS, NVIDIA Isaac) and experimental validation on PRISMA Lab platforms such as ANYmal D.</p>		<h3>TOOLS</h3> <p>Simulation & Middleware: ROS (Noetic), Gazebo, NVIDIA Isaac, Matlab/Simulink Languages & Libraries: Python, C++, Ultralytics YOLO Other: GitHub, Docker Robot: ANYmal D</p> <h3>SUPERVISOR</h3> <p>Prof. Fabio Ruggiero - fabio.ruggiero@unina.it</p> <h3>TECHNICAL SUPERVISOR</h3> <p>Eng. Riccardo Aliotta – riccardo.aliotta@unina.it</p> <h3>KEYWORDS</h3> <p>Mobile manipulation; legged robotics; planning.</p>	
<h3>EXAMPLES / POSSIBLE ACTIVITIES</h3> <ul style="list-style-type: none">• Track 1 – Weed Species Uprooting with Mobile Manipulator Develop robust control algorithms for a mobile manipulator, using convolutional neural networks for identifying the target and a manipulator mounted on ANYmal D for uprooting it.• Track 2 – Self-Collision-Aware Path Planning for Mobile Manipulator Develop path-planning algorithms for a manipulator mounted on a mobile platform that account for both base and arm poses, achieving collision-free and feasible motions in cluttered environments.			
<h3>PREREQUISITES / NOTES</h3> <p>Recommended courses: Field and Service Robotics, Robot Interaction Control, Robotics Lab.</p> <p>Recommended skills: Python/C++, familiarity with ROS/ROS2.</p> <p>Target degree: Master’s in Automation and Robotics Engineering.</p>		<h3>RELATED BIBLIOGRAPHY</h3> <ul style="list-style-type: none">• ROS Documentation – https://docs.ros.org/• Gazebo Simulator – https://gazebosim.org/• NVIDIA Isaac – https://developer.nvidia.com/isaac/lab• Ultralytics YOLO – https://www.ultralytics.com/yolo	

[DynLeg – 8] – Feeling the Contact: Force Control for Robots in Changing Environments

Thesis sheet · PRISMA Lab



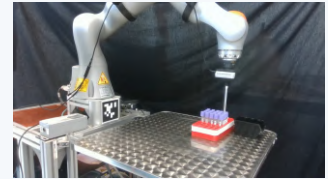
ANYmal D pushing on silage



ANYmal D pushing open a door



Quadruped acting as a guide dog



KUKA in a force-based interaction

THESIS OVERVIEW

Force control is crucial when robots interact with environments whose mechanical properties are uncertain, variable, or only partially observable, such as soil, vegetation, doors, tools, or deformable materials.

This research area focuses on the development of force-aware control algorithms for various interaction tasks, both for mobile- and fixed-base robot manipulators.

Topics include force-aware interaction in dynamic and discontinuous environments.

Control methods leverage optimization techniques, classical force control schemes, and data-driven approaches.

The work includes simulation (Gazebo/ROS, NVIDIA Isaac) and experimental validation on PRISMA Lab platforms such as ANYmal D and KUKA iiwa7.

TOOLS

Simulation & Middleware: ROS (Noetic), Gazebo, NVIDIA Isaac, Matlab/Simulink

Languages & Libraries: Python, C++

Other: GitHub, Docker

Robot: ANYmal D, KUKA iiwa 7

SUPERVISOR

Prof. Fabio Ruggiero - fabio.ruggiero@unina.it

TECHNICAL SUPERVISOR

Eng. Riccardo Aliotta – riccardo.aliotta@unina.it

KEYWORDS

Force control; dynamic environment.

EXAMPLES / POSSIBLE ACTIVITIES

• Track 1 – Precise Force-based Vegetable Species Uprooting

Development of a force-based algorithm to uproot different vegetable specimens, considering the force required to uproot them without tearing or damaging the specimen.

• Track 2 – Mobile Manipulator Control for Discontinuous Environment Interaction

Development of control algorithms for mobile manipulators, enabling force interaction with environments whose properties can change in an unpredictable and discontinuous way, such as drilling or pulling tasks.

PREREQUISITES / NOTES

Recommended courses: Field and Service Robotics, Robot Interaction Control, Robotics Lab.

Recommended skills: Python/C++, familiarity with ROS/ROS2, familiarity with NVIDIA Isaac.

Target degree: Master's in Automation and Robotics Engineering.

RELATED BIBLIOGRAPHY

- ROS Documentation – <https://docs.ros.org/>
- Gazebo Simulator – <https://gazebo.org/>
- NVIDIA Isaac – <https://developer.nvidia.com/isaac/lab>

[DynLeg – 9] – Touch to Understand: Active Visuo-Tactile Learning for Robust Deformable Object Manipulation

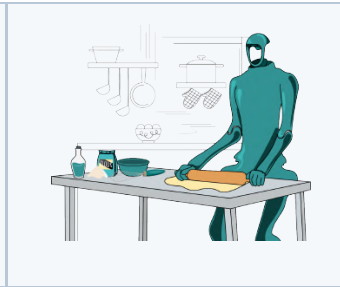
Thesis sheet · PRISMA Lab



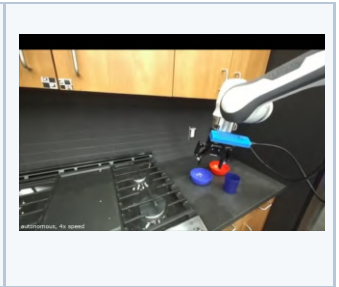
Franka Fr3 – Bimanual Setup



Haption Virtuose: Compact Force-Feedback Devices Desktop 6D



Robot manipulation of deformable objects via tool interaction



Physical intelligence in kitchen environment

THESIS OVERVIEW

This thesis focuses on active visuo-tactile learning for the manipulation of deformable objects such as cloth, cables, bags, soft packaging, or food-related items in household environments. Unlike rigid objects, deformable objects continuously change shape during interaction, making perception and manipulation highly uncertain, especially under occlusions, clutter, or partial observability.

Domestic robots still struggle with these tasks because vision alone is often insufficient to estimate the state, geometry, and physical properties of soft objects. Humans naturally combine seeing and touching to reduce uncertainty before and during manipulation. Similarly, this thesis will investigate how robots can actively interact with objects and exploit multimodal sensing to improve their understanding of the scene.

The expected outcome is a perception and learning framework integrating vision, tactile sensing, and robot interaction data. Depending on the selected track, the work may include deformable object state estimation, active exploration policies, self-supervised data collection, tactile-assisted manipulation, and validation in simulation and/or on real robotic platforms such as Franka FR3 arms or KUKA LBR iiwa.

TOOLS

Simulation & Robotics: MuJoCo, NVIDIA Isaac, Gazebo, or PyBullet ; Intel RealSense RGB/RGB-D cameras ; Tactile sensing devices and 6-axis F/T sensors; Franka Research 3 (FR3) arms, KUKA LBR iiwa 14

Methods: Deep learning; Transformer-based multimodal fusion; Self-supervised learning; Physics-informed learning; Representation learning

Programming / ML: Python; PyTorch / TensorFlow; ROS / ROS2; Large pre-trained Vision-Language-Action (VLA) models (OpenVLA-OFT/Octo/ π 0)

SUPERVISOR

Prof. Mario Selvagio - mario.selvagio@unina.it

KEYWORDS

VLA; Learning bimanual manipulation; active perception; Franka FR3; Haption Virtuose; imitation learning; LeRobot.

EXAMPLES / POSSIBLE ACTIVITIES

• Track 1 – Visuo-Tactile State Estimation for Deformable Objects

Develop multimodal perception models combining visual and tactile information to estimate the state, shape, or configuration of deformable objects such as cloth, cables, or soft packaging.

• Track 2 – Active Exploration for Uncertainty Reduction

Design active sensing strategies where the robot interacts with the object to improve perception quality, reduce uncertainty, and recover information not available from vision alone.

• Track 3 – Self-Supervised Learning from Robot Interaction Data

Build datasets of robot-object interactions and train self-supervised models to predict object deformation, contact states, slippage, or manipulation outcomes.

• Track 4 – Robust Manipulation under Occlusion and Clutter

Evaluate perception and manipulation robustness in challenging scenarios, such as partial occlusions, cluttered scenes, uncertain contacts, or tactile-assisted object handling.

PREREQUISITES / NOTES

Recommended courses: Robotics Lab, Robot Interaction Control, Field and Service Robotics, Intelligent Robotics.

Recommended skills: Python and PyTorch; ROS 2; Robot kinematics and Impedance control; Experience with neural networks or multimodal learning is a strong plus.

RELATED BIBLIOGRAPHY

[1] J. Bohg *et al.*, "Interactive Perception: Leveraging Action in Perception and Perception in Action," in *IEEE Transactions on Robotics*, vol. 33, no. 6, pp. 1273-1291, Dec. 2017, doi: 10.1109/TRO.2017.2721939.

[2] Ahmet E. Tekden, et al., "Object and relation centric representations for push effect prediction," in *Robotics and Autonomous Systems*, Volume 174, 2024, 104632, ISSN 0921-8890, <https://doi.org/10.1016/j.robot.2024.104632>.

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[DynLeg-10] – Thinking Ahead: Long-Horizon Planning and Robust Control for Non-Prehensile Deformable Object Manipulation



Thesis sheet · PRISMA Lab

<p>Franka Fr3 – Bimanual Setup</p>	<p>Open PI architecture</p>	<p>Robot manipulation of deformable objects via tool interaction</p>	<p>Physical intelligence in kitchen environment</p>
<p>THESIS OVERVIEW</p> <p>This thesis focuses on long-horizon planning and robust control for robots manipulating deformable objects in uncertain household environments. The target tasks involve non-prehensile actions such as pushing, sliding, flattening, repositioning, or recovering from failed manipulation attempts.</p> <p>Domestic environments are dynamic and partially unpredictable, especially when robots interact with soft or deformable objects whose motion is difficult to model accurately. Traditional robotic pipelines may fail because manipulation outcomes are uncertain and errors can accumulate over long action sequences. The motivation of this thesis is to enable robots to reason over future consequences, adapt their plans online, and recover from unexpected outcomes.</p> <p>The expected outcome is a planning and control framework that integrates learning-based manipulation models with robust decision-making strategies. Depending on the selected track, the thesis may address long-horizon planning, uncertainty-aware control, learned world models, sim-to-real transfer, recovery strategies, or Vision–Language–Action models for guiding manipulation from language instructions and visual observations. Validation will be carried out in simulation and, where feasible, on real robotic platforms.</p>		<p>TOOLS</p> <p>Programming: Python; ROS / ROS2; C++ (optional); Haption Virtuose</p> <p>Simulation & Robotics: NVIDIA Isaac, MuJoCo, Gazebo, PyBullet; Robotic manipulation platforms</p> <p>Methods: Motion planning; Model Predictive Control (MPC); Reinforcement Learning (RL); Task and Motion Planning (TAMP); Vision–Language–Action models; Sim-to-real transfer methods</p> <p>SUPERVISOR</p> <p>Prof. Mario Selvaggo - mario.selvaggo@unina.it</p> <p>KEYWORDS</p> <p>Robot planning, robotic manipulation, deformable objects, non-prehensile manipulation, long-horizon planning, uncertainty-aware control, reinforcement learning, sim-to-real transfer, embodied intelligence, VLA systems.</p>	
<p>EXAMPLES / POSSIBLE ACTIVITIES</p> <ul style="list-style-type: none"> • Track 1 – Long-Horizon Planning for Deformable Object Manipulation Design planning algorithms for multi-step manipulation tasks involving deformable objects, such as flattening dough, repositioning soft objects, or executing household manipulation sequences. • Track 2 – Learning-Based World Models for Manipulation Planning Integrate learned manipulation or world models into planning pipelines to predict the effects of pushing, sliding, flattening, or other non-prehensile actions. • Track 3 – Uncertainty-Aware Control for Contact-Rich Interaction Develop robust controllers that account for uncertain object properties, disturbances, and imperfect predictions during deformable object manipulation. • Track 4 – Sim-to-Real and Recovery Strategies Train and evaluate manipulation policies in simulation, investigate sim-to-real transfer, and develop recovery strategies for failed or uncertain manipulation attempts. • Track 5 – VLA-Guided Robotic Manipulation Explore the use of Vision–Language–Action models to guide long-horizon manipulation tasks from language instructions and visual observations. 			
<p>PREREQUISITES / NOTES</p> <p>Recommended courses: Robotics Lab, Robot Interaction Control, Field and Service Robotics, Intelligent Robotics, Motion planning.</p> <p>Recommended skills: Python and PyTorch; Basic robotics knowledge; Control systems or motion planning fundamentals; Useful but not mandatory: Reinforcement learning experience; Optimization or control theory background.</p>		<p>RELATED BIBLIOGRAPHY</p> <p>[1] openpi codebase (Physical Intelligence) – https://github.com/Physical-Intelligence/openpi</p> <p>[2] Black et al., "pi0: A Vision-Language-Action Flow Model", Physical Intelligence 2024 - https://physicalintelligence.company/blog/pi0</p> <p>[3] Kim et al., "OpenVLA: An Open-Source Vision-Language-Action Model", CoRL 2024 – https://openvla.github.io</p>	