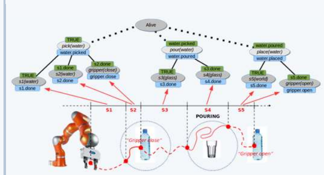
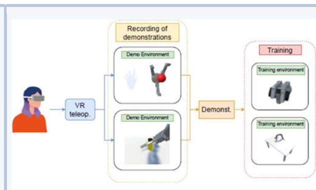
[AICRob-1] Incremental Task Learning and Collaborative Robot Manipulation

Thesis sheet · PRISMA Lab

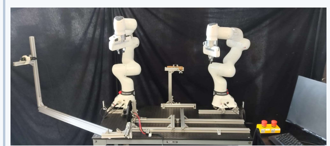
Kinesthetic teaching



Structured Task Segmentation



Virtual Demonstrations



Franka Emika bimanual Platform

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THESIS OVERVIEW

Incremental task learning enables collaborative robots to acquire increasingly complex manipulation skills through interaction, demonstration, and adaptive experience accumulation. Instead of programming robot behaviours manually, the robot incrementally learns structured manipulation tasks and progressively refines its capabilities through observation, execution monitoring, and feedback.

This thesis focuses on the development of methods for incremental learning of manipulation tasks in collaborative robotic systems. The student will investigate techniques for kinesthetic teaching, multimodal monitoring of task execution, and continual adaptation of learned skills through sensory feedback and AI-based models. Application scenarios include structured manipulation activities such as object handling, tool usage, and collaborative interaction. The work includes software development and experimental validation on collaborative manipulation platforms available at PRISMA Lab, including Franka-based systems.

TOOLS

Hardware Platforms: Franka Emika bimanual collaborative manipulation platform
Software & Middleware: ROS/ROS2, Franka Control Interface (FCI), MoveIt
Languages & Libraries: C++, Python (for AI/learning modules)
AI / Learning Frameworks: PyTorch/TensorFlow (optional, depending on the selected track)

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KEYWORDS

kinesthetic learning; collaborative manipulation; human–robot interaction; robot learning from demonstration; structured manipulation tasks; collaborative robotics

EXAMPLES / POSSIBLE ACTIVITIES

- Development of kinesthetic teaching methods for collaborative manipulators, enabling users to physically guide the robot through structured manipulation tasks.
- Design of control and interaction strategies for learning manipulation skills involving grasping, tool use, and force-feedback-based execution.
- Integration of multimodal demonstrations, including physical guidance, visual inputs, speech commands, and force/torque sensing, for incremental task learning.
- Development of continual learning frameworks for robotic manipulation, using generative models to support policy generation, generalization, and memory of previously learned tasks.
- Experimental validation of learned manipulation skills on collaborative robotic platforms such as KUKA IIWA or Franka Emika systems.

PREREQUISITES / NOTES

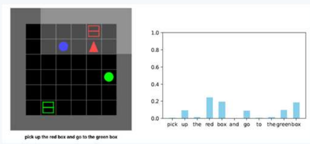
Recommended for Master's students in Automation Engineering, Robotics, Computer Engineering, or Computer Science. Basic knowledge of robotics, control, programming, and robot manipulation is recommended.

RELATED BIBLIOGRAPHY

Kinesthetic teaching and attentional supervision of structured tasks in human–robot interaction: https://link.springer.com/article/10.1007/s10514-018-9706-9
Incremental learning from virtual demonstrations and task composition for robotic manipulation: https://www.sciencedirect.com/science/article/pii/S0921889025003719

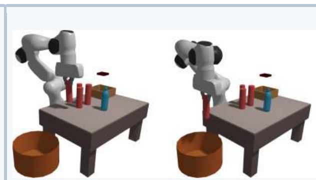
[AICRob 2] Generative AI for Robot Reasoning, Planning and Execution

Thesis sheet · PRISMA Lab

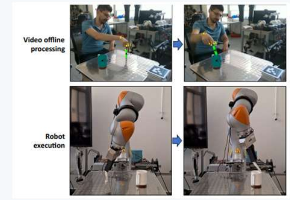


Attentional distribution over objects

Robot interpreting scenes via VLMs



Robot in a tabletop scenario



Training in real world

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THESIS OVERVIEW

Generative AI models are increasingly transforming the way robots perceive, reason, plan, and interact with users. Large Language Models, Vision-Language Models, and multimodal generative models can support natural-language task specification, visual grounding, symbolic reasoning, execution monitoring, explanation of robot decisions, and rapid adaptation to new operational contexts.

This thesis focuses on the integration of generative AI methods with robotic reasoning, planning, and execution frameworks. The student will investigate how language and multimodal models can support task specification, robot decision-making, and adaptive execution in real-world robotic scenarios.

The work may address the translation of natural-language instructions into executable robot plans, the grounding of user requests into object-centric manipulation tasks, execution monitoring and explanation, and continual adaptation and rapid robot reconfiguration. The work may involve the development of software architectures integrating LLMs, VLMs, symbolic and motion planners, ontologies, knowledge graphs, and robotic execution frameworks. Application scenarios include language-guided object manipulation, scene understanding and task planning, and flexible robotic assembly and disassembly tasks.

TOOLS

Hardware Platforms: Collaborative robots or mobile manipulators; RGB-D cameras; force/torque sensors; possible simulated robotic platforms.
Software & Middleware: ROS2, MoveIt2, RViz, Unity, CoppeliaSim, AIPlan4EU, Protégé.
Languages & Libraries: Python, OWL, planning/domain modelling languages.
AI / Generative Models: LLMs, VLMs, VLA models, multimodal generative models.
Planning / Knowledge Representation: Symbolic planning, motion planning, ontologies

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KEYWORDS

generative AI; large language models; vision-language models; robot reasoning; task planning; motion planning; explainable AI; knowledge graphs; ontologies; multimodal learning; learning from demonstration; robot manipulation; human–robot interaction

EXAMPLES / POSSIBLE ACTIVITIES

- Development of a robotic system that localizes and manipulates objects from natural-language commands using Vision-Language Models and RGB-D perception.
- Integration of LLMs, symbolic planning, and motion planning to translate natural-language goals into valid and executable robot plans.
- Design of explainable planning and execution-monitoring modules able to justify robot decisions, check plan validity, and interpret execution logs.
- Use of generative and multimodal AI models to support skill generalization, policy generation, memory, and adaptation of previously learned robot behaviours.
- Design of ontology- and knowledge-graph-based architectures for rapid robot reconfiguration in structured industrial assembly or disassembly scenarios.
- Integration of generative models with symbolic domain representations to adapt robot behavior dynamically to new tasks, components, or workcell configurations.

PREREQUISITES / NOTES

Recommended for Master's students in Automation Engineering, Robotics, Computer Engineering, or Computer Science. Basic knowledge of robotics, programming, artificial intelligence, and machine learning is recommended.

RELATED BIBLIOGRAPHY

Combined Text-Visual Attention Models for Robot Task Learning and Execution: https://link.springer.com/chapter/10.1007/978-3-031-80607-0_18

[AICRob 3] Planning and Flexible Execution for Intelligent Robots

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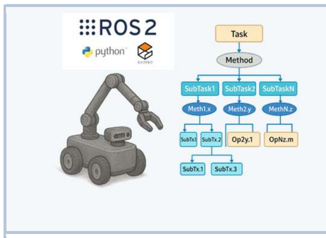
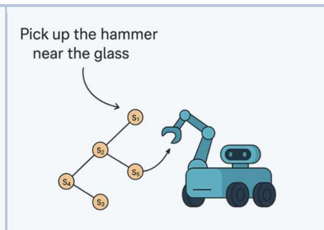
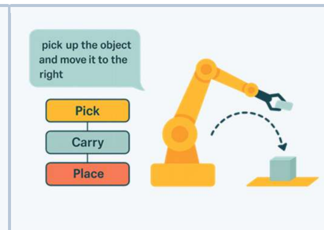


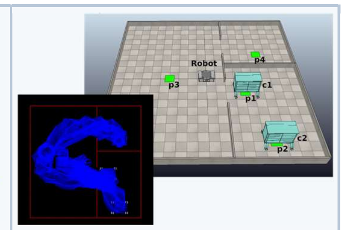
Robot structured task



Robot interpreting commands



Task plan for robot manipulation



Example of a task and motion plan

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THESIS OVERVIEW

Plan-based autonomy enables intelligent robots to deliberate, act, monitor their execution, and adapt their behavior while performing complex tasks in dynamic environments. In robotic systems, high-level task planning and low-level motion planning are strongly interdependent: a valid symbolic plan must correspond to feasible robot motions, while geometric constraints may affect the choice of actions and task structure.

This thesis focuses on the design and development of planning-based architectures for autonomous robots, with particular attention to Task and Motion Planning, hierarchical planning, execution monitoring, replanning, and language-guided reasoning. The student may investigate methods for combining symbolic planning and sampling-based motion planning, using learned or language-based heuristics to guide search, and integrating planning systems with robotic execution frameworks.

Application scenarios include mobile manipulators performing structured pick-and-delivery tasks, robots translating natural-language goals into validated plans, hierarchical task execution with dynamic task insertion, and adaptive replanning based on execution feedback, human-robot collaborative execution of structured tasks. The work may include software development, simulation, comparison with state-of-the-art baselines, and integration with ROS-based robotic platforms.

TOOLS

Hardware Platforms: Mobile manipulators; simulated robotic manipulation or navigation platforms.
Software & Middleware: ROS/ROS2, MoveIt2, RViz, Gazebo, CoppeliaSim, AIPlan4EU, custom graph-based execution engines.
Languages & Libraries: Python, C++, PDDL, HDDL.
Planning / AI Frameworks: Task and Motion Planning, symbolic planning, sampling-based motion planning, OMPL, hierarchical planning, Behavior Trees, Reinforcement Learning, LLM-based planning guidance, knowledge graphs, execution monitoring and replanning.

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KEYWORDS

plan-based autonomy; task and motion planning; symbolic planning; motion planning; hierarchical planning; execution monitoring; replanning; mobile manipulation; sampling-based planning; learned heuristics; language-guided planning; behavior trees

EXAMPLES / POSSIBLE ACTIVITIES

- Development of a combined Task and Motion Planning system for mobile manipulators engaged in structured pick-and-delivery tasks.
- Integration of symbolic planning and sampling-based motion planning to generate high-level action sequences associated with feasible collision-free trajectories.
- Design of planning systems that translate natural-language goals into executable robot plans using LLMs, symbolic domain models, and motion planning.
- Development of explainable planning and execution-monitoring modules able to justify robot decisions, inspect plan validity, and interpret execution logs.
- Development and evaluation of language-guided planning or replanning methods, using LLMs or knowledge graphs to guide the search process.
- Learning of planning heuristics from demonstrations, execution data, or reinforcement learning to improve the efficiency of Task and Motion Planning.
- Design of hierarchical planning architectures with dynamic task insertion, process or behavior graphs, Behavior Trees, and runtime monitoring.
- Experimental evaluation of planning and replanning methods in simulation environments such as Gazebo or CoppeliaSim, with comparison against state-of-the-art baselines.

PREREQUISITES / NOTES

Recommended for Master's students in Automation Engineering, Robotics, Computer Engineering, or Computer Science. Basic knowledge of robotics, algorithms, planning, programming, and artificial intelligence is recommended. Useful skills include Python or C++ programming, ROS/ROS2, motion planning, symbolic planning.

RELATED BIBLIOGRAPHY

A Robotic Cognitive Control Framework for Collaborative Task Execution and Learning: https://onlinelibrary.wiley.com/doi/full/10.1111/tops.12587
A rapidly-exploring random trees approach to combined task and motion planning: https://www.sciencedirect.com/science/article/pii/S0921889022001385

[AICRob 4] Intelligent Multi-Robot Teams for Exploration and Cooperation

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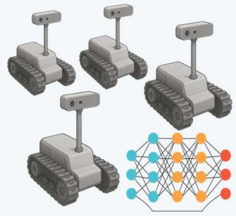
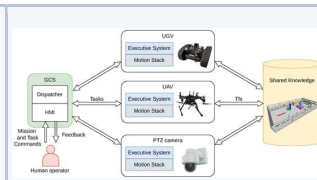
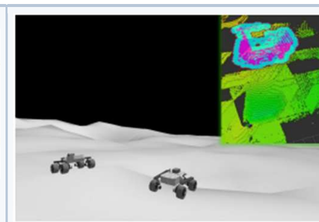


Coordinated swarm of robots

Lunar Environment



Mult-robot team of intelligent agents



Simulation of lunar rovers

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THESIS OVERVIEW

Intelligent multi-robot systems enable teams of autonomous robots to cooperate in complex tasks such as exploration, distributed sensing, cooperative transport, and planetary surface mapping. Compared to single-robot systems, multi-robot teams can improve robustness, scalability, and coverage, but they also introduce challenges related to coordination, communication constraints, task allocation, decentralized decision-making, and limited computational resources.

This thesis focuses on the design and development of intelligent methods for cooperative multi-robot autonomy in realistic exploration and collaboration scenarios. The student may investigate approaches based on Multi-Agent Deep Reinforcement Learning, distributed coordination, and autonomous navigation. Application domains include cooperative exploration with mobile robots, efficient learning of collaborative behaviors under communication and computation constraints, and the development of mini robotic systems for lunar soil and cave exploration in collaboration with aerospace research partners.

The work may include simulation, software development, AI-based coordination strategies, and experimental validation in realistic robotic environments.

TOOLS

Hardware Platforms: Multi-robot mobile platforms; mini robotic systems for exploration; possible lunar exploration prototypes.
Software & Middleware: ROS/ROS2, Gazebo, CoppeliaSim, Unity ML-Agents, OMPL.
Languages & Libraries: Python, C++, PyTorch.
AI / Planning / Learning Frameworks: Multi-Agent Reinforcement Learning, Deep Reinforcement Learning, task and motion planning, autonomous navigation algorithms.

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KEYWORDS

multi-robot systems; cooperative robotics; multi-agent reinforcement learning; autonomous exploration; distributed coordination; task and motion planning; lunar robotics; mobile robots; robot teams; scalable autonomy

EXAMPLES / POSSIBLE ACTIVITIES

- Design and simulation of Multi-Agent Deep Reinforcement Learning strategies for cooperative mobile robots, considering limited communication and computational resources.
- Development of cooperative robotic behaviors for tasks such as exploration, distributed sensing, cooperative transport, or distributed manipulation.
- Evaluation of learning-based coordination methods in realistic simulation environments, focusing on scalability, robustness, and efficiency.
- Design and development of mini robotic systems for lunar soil and cave exploration, including locomotion, sensing, and autonomous navigation.
- Development of software modules for collaborative task execution, information sharing, and AI-based decision-making in multi-robot exploration scenarios.
- Integration of task and motion planning methods for cooperative missions in challenging or partially known environments.

PREREQUISITES / NOTES

Recommended for Master's students in Automation Engineering, Robotics, Computer Engineering, or Computer Science. Basic knowledge of robotics, control, programming, and artificial intelligence is recommended. Depending on the selected activity, useful skills include Python or C++ programming, ROS/ROS2, simulation environments, machine learning, and mobile robot navigation.

RELATED BIBLIOGRAPHY

H-CoRE: A Cooperative Framework for Heterogeneous Multi-Robot Exploration and Inspection: https://www.mdpi.com/2504-446X/10/4/232

A multi-robot deep Q-learning framework for priority-based sanitization of railway stations: https://link.springer.com/article/10.1007/s10489-023-04529-0