Uncertainty Aware Trajectory Prediction for Dynamic Grasping

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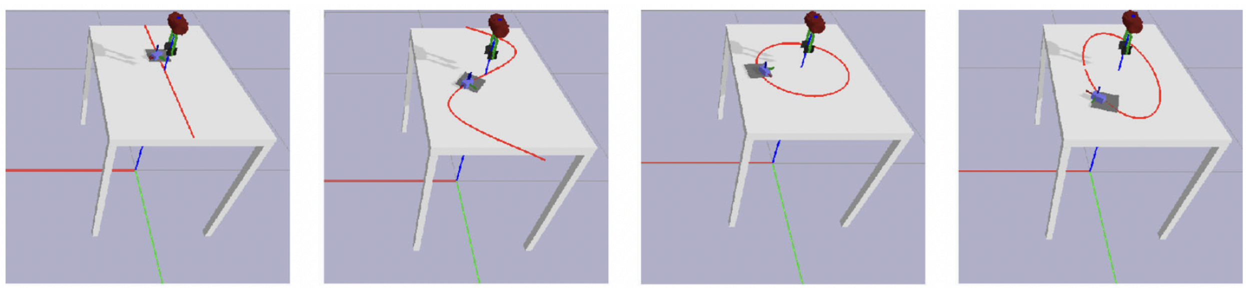
Scope:	Project thesis / Master’s thesis by arrangement
Start:	From mid October or by arrangement



Source: Improving reinforcement learning based moving object grasping with trajectory prediction. Intelligent Service Robotics, 2024

Motivation

Imagine several objects moving on a conveyor belt, some of those might be occluded from time to time. How can we design robust manipulation algorithms for such dynamic environments? Achieving reliable grasping of moving objects still remains a challenging problem, as it requires addressing two closely related tasks: accurately predicting the object’s motion and estimating how environmental factors influence graspability [1,2,3].

A key component is estimating the object’s trajectory along with its uncertainty. While many approaches for trajectory prediction have been proposed [4,5], existing methods often do not capture uncertainty comprehensively. In particular, uncertainty arising from long temporal prediction horizons and uncertainty introduced by the environment are rarely considered jointly. While the relation between uncertainty and the *prediction horizon* is quite systematic - the further we look into the future, the more uncertain is our estimate,- *environmental factors* can either constrain an object’s motion and with this decrease uncertainty estimates or increase uncertainty estimates, for example when objects become occluded and are temporarily out of sight. Accounting for both sources of uncertainty is therefore critical for reliable motion prediction and successful grasp execution.

Task Description

The goal of this thesis is to enable learning-based grasping methods to operate in dynamic environments with only minimal adaptation. Building on existing trajectory prediction approaches, such as BiTraP [4], these methods will be adapted to the robotic manipulation setting, where an object is moving on a table - executing different movement patterns: linear, sinusoidal, rectangular and circular.
The first objective is to model and predict geometrically constrained object trajectories, including linear, sinusoidal, circular, and rectangular motion patterns, together with their uncertainty estimates over time. The second objective is to identify and represent environmental factors that influence the future motion of an object and thus also the uncertainty of the object's future location. With this, we wish to learn about the graspability of an object at a particular location, given the object’s past trajectory as well as its environment.
Based on these trajectory and uncertainty estimates, the predicted motion and its associated uncertainty will be incorporated into the robot’s state representation to improve decision-making during grasp execution. The aim is to enable the robot to reason not only about an object’s predicted future trajectory, but also about where and when the object can be grasped most reliably.

Requirements

- High motivation to solve robotic challenges and to work in an international team.
- Exceptionally high level of personal commitment and a self-driven working style.
- Strong proficiency in Python programming and version control using GitHub for reproducible software development. Familiarity with C++ is considered an advantage. Experience with robotics software frameworks such as ROS, Isaac Sim, and PyBullet is a plus.
- Basic understanding of robotic manipulation, including grasp stability, contact dynamics, and kinematic and joint-space control is a plus.

References

[1] Xu, B., Hassan, T., & Hussain, I. (2024). Improving reinforcement learning based moving object grasping with trajectory prediction. *Intelligent Service Robotics*, *17*(2), 265-276.

[2] Jia, Y., Xu, J., Jayaraman, D., & Song, S. (2024, August). Dynamic grasping with a learned meta-controller. In *2024 IEEE 20th International Conference on Automation Science and Engineering (CASE)* (pp. 3608-3615). IEEE.

[3] Boyalakuntla, K., Boularias, A., & Yu, J. (2025, October). KARL: Kalman-filter assisted reinforcement learner for dynamic object tracking and grasping. In *2025 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)* (pp. 2819-2826). IEEE.