Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Master Thesis
IDSC-MZ-MP-1

Safe guaranteed domain exploration with autonomous robots

Keywords: Gaussian Processes, Active learning, Bayesian optimization, model predictive control (MPC), Issac sim simulator

Project description:

Motivation: In many autonomous navigation applications, the robot must interact with the environment to learn and complete tasks. Furthermore, these applications are safety-critical, and crashes cannot be afforded. This necessitates the safe learning of the unknown environment in order to achieve the task objective (e.g., detecting a leak or mapping an area). For example, consider an application of safe exploration in a warehouse with a wheeled robot to identify the source of a gas leak.

The problem has numerous challenges which stems from providing guarantees with unknown objectives, unknown constraints, and typically nonlinear dynamics of the robots. We have developed a theoretical framework addressing safe exploration [1]. The main objective of the project is to deploy it in more realistic simulators and extend the framework towards tasks with unknown rewards, e.g., active learning or Bayesian optimization. The developed framework will have a lot of diverse applications, such as mapping in an unknown environment, executing tasks in the presence of unknown obstacles, industrial inspection, surveillance, and more.

The project may include the following packages:

- Basics:
    - Understanding the safe exploration methods [1] and MPC
    - Familiarize with the Issac sim simulator, including experimenting with various robots, sensor configurations and environment creation
- Algorithm:
    - Modelling of the unknown environment
        - Modelling of apriori unknown constraints, such as determining suitable kernel for modeling of corners and edges of warehouses

        - Modelling of the unknown utility function which is used to define a task
        - Determining sensory feedback for utility and constraints learning
    - Develop an algorithm for safe exploration while maximizing the unknown objective
    - (Optional) Derive convergence guarantees to the optimal location in finite time
- Experimental:
    - Implement the algorithm in python; familiarize with PyTorch, Acados/Casadi
    - Run the experiment in Issac sim simulation, e.g., identifying a leak detection in exploring a warehouse with a lidar sensor
    - Improve the developed algorithm such as changes in the tools that can let the robot go close to the constraints
    - Make the code efficient, implement tests and document it
- (Extensions)
    - Similar experiment with different robots, e.g., Drones
    - Mapping of an unknown area with Drones
    - Compare uncertainty modelling with Bayesian neural networks

Prerequisites:

The project is open for a Master's thesis. An ideal candidate should have experience working with simulators such as Issac sim or Gazebo, ML libraries such as PyTorch, and preferably have done the probabilistic AI and MPC course. Since the project is challenging and connects different areas, the student can anticipate a steep learning curve while diving into various fields.

Contact:

If you are interested, please contact Manish Prajapat (manishp@ai.ethz.ch) or Johannes Kohler (jkoehle@ethz.ch).

Reference:

[1] Safe Guaranteed Exploration for Non-linear Systems

(link: https://arxiv.org/abs/2402.06562)