Safety Query: 3D Collision Mass Maps for Human-Robot Interaction

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Background

Safe human-robot interaction requires reliable estimation of collision forces during physical contact. A key quantity for this estimation is the effective robot mass, which depends on the robot configuration, collision direction, payload, and workspace location. Recent work introduced Collision Mass Maps (CMMs) [1], a data-driven approach for predicting the effective mass across the workspace and deriving safe robot velocities according to ISO 10218-2. However, existing formulations are mainly limited to simplified workspace representations. For redundant manipulators, the same end-effector position can correspond to different joint configurations and therefore different collision behavior.

Description

This project aims to extend Collision Mass Maps to full 3D workspaces and redundant robotic manipulators. The goal is to develop a data-driven model that predicts the effective robot mass based on 3D collision location, robot configuration, and possibly collision direction. The extended map should enable more accurate safety assessment for collaborative robots operating in complex workspaces.

A main challenge is the efficient collection of informative collision measurements, since exhaustive sampling in high-dimensional spaces is impractical. Therefore, the project will investigate uncertainty-aware learning methods, such as Gaussian process regression, and active sampling strategies, such as Bayesian optimization, to construct the extended CMM with a limited number of measurements. The resulting framework will be evaluated on a real robotic platform.

This project requires interaction with robotic hardware and therefore regular on-site presence.

Tasks

- Review literature on effective mass estimation, collision force prediction, and robot safety.
- Study the existing Collision Mass Map framework and its limitations.
- Extend the CMM representation to 3D workspaces and redundant robot configurations.
- Develop an efficient sampling strategy for selecting informative measurement points.
- Evaluate prediction accuracy, underestimation risk, and measurement efficiency in simulation and real experiments.

References

[1] Julian Balletshofer, Robin Jeanne Kirschner, and Matthias Althoff. Collision mass map for safe and efficient human-robot interaction. In *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pages 6320–6327, 2025.

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Research project:

Type:
BA/MA/GR/SA

Research area:
Safe Human-Robot Interaction, Redundant Manipulators, Data-Driven Robot Safety

Programming language:
Python, C++

Required skills:
Programming in Python/C++, basic robotics and robot kinematics knowledge

Language:
English

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