MEE 5114 Advanced Control for Robotics

Course Final Project
Spring 2023
Due June 15, 2023

Requirement and Deliverables:

- Students should work in a team of two or three students.
- Each team should choose one of the following two problems. You will be provided with urdf file and a basic quadruped controller.
- Some of the questions are open-ended, and you do not need to solve all the subproblems. You are expected to read papers and search and re-search online.
- **Reports:** Each team should submit one report along with your solution codes. The report should provide all the background information, problem formulation (as control or optimization problem), existing methods, your proposed solution, your results, and discussions.

Problem I: System identification for legged robots

Having accurate dynamics model is critical in achieving agile and dynamic locomotion of legged robots. Practically speaking, parameters involved in the dynamics model are difficult to acquire precisely from outputs from mechanical design. System identification is an important tool to address this issue.

Given a fixed-base single-leg or a floating-base full quadruped model as URDF file, design simulation experiments and system identification algorithms to identify the dynamics parameters, compare the identified parameters with the ground truth from the URDF to justify the performance.

Objectives:

1. Identify the dynamical parameters of a fixed-base single-leg system, including for example the mass and inertia of each link.
2. Identify the dynamical parameters of a floating-base quadruped system, including for example the mass and inertia of all the legs as well as the base.

(a) Consider a single leg of the quadruped robot with fixed base, integrate the simulator with a leg controller, ensure the leg can execute desirable motions as commanded. Collect data (joint torque, position, etc) needed for system identification via simulating the single-leg system.

(b) Design and implement appropriate system identification algorithms to identify the dynamical parameters of the single leg. Compare the identified parameters with the ground truth from the URDF model, and analyze the performance. Test your algorithm when there is measurement noise and discuss your results.

(c) (bonus) Come up with a way to identify the entire quadruped model parameters (including all the links, and the floating base body). Your measurements can be anything that is possibly available in reality (e.g. joint position, velocity, torque, IMU data, ground reaction force (use only when it is absolutely necessary)). Test your methods and discuss the results.

References:

1. C. G. Atkeson, C. H. An, and J. M. Hollerbach, "Estimation of inertial parameters of manipulator loads and links," The International Journal of Robotics Research, vol. 5, no. 3, pp. 101–119, 1986.
2. P. Wensing, S. Kim, and J.-J. E. Slotine, "Linear matrix inequalities for physically consistent inertial parameter identification: A statistical perspective on the mass distribution," IEEE Robot. Autom. Lett., vol. 3.
3. no. 1, pp. 60–67, Jan. 2018.K. Ayusawa, G. Venture, and Y. Nakamura, "Identifiability and identification of inertial parameters using the underactuated base-link dynamics for legged multibody systems," Int. J. of Robotics Research, vol. 33, no. 3, pp. 446–468, 2014.
4. C. D. Sousa and R. Cortesao, "Physical feasibility of robot base inertial parameter identification: A linear matrix inequality approach," Int. J. of Robotics Research, vol. 33, no. 6, pp. 931–944, 2014.

Problem II Swing trajectory plan and tracking control

Safe and dynamically feasible plan and accurate tracking of the swing foot trajectory play a fundamentally important role in achieving stable and reliable quadruped locomotion. This project focuses on the planning and control for the swing trajectories.

Objective:

Given a fixed-base single-leg quadruped model (URDF file), design the foothold planning and associated tracking control scheme to generate appropriate swing motion for the platform.

(a) Given an initial and a final position/pose of the foot-tip, find a feasible trajectory connecting these two configurations. Design a tracking controller that can track the planned trajectory. Evaluate the performance via detailed analysis and simulation studies of the results.

(b) In the presence of known obstacles, plan the trajectory that is collision-free. You can choose different kinds of obstacles of your choice. Simulate and test the overall system including your collision avoidance leg swinging planner and tracking controller and discuss your results.

(c) (bonus) Consider the full quadruped dynamics model, integrate the proposed swinging planner and controller with a quadruped controller to evaluate the performance in an environment with terrain obstacles.

References:

1. M. Kelly, "An introduction to trajectory optimization: How to do your own direct collocation," SIAM Review, vol. 59, no. 4, pp. 849–904, 2017.
2. D. Kim, J. D. Carlo, B. Katz, G. Bledt, and S. Kim, "Highly Dynamic Quadruped Locomotion via Whole-Body Impulse Control and Model Predictive Control," arXiv.org, Sep. 2019
3. Farbod Farshidian, Michael Neunert, Alexander W Winkler, Gonzalo Rey, and Jonas Buchli. An efficient optimal planning and control framework for quadrupedal locomotion. In 2017 IEEE International Conference on Robotics and Automation (ICRA), 93–100. IEEE, 2017.
4. J. Schulman, Y. Duan, J. Ho, A. Lee, I. Awwal, H. Bradlow, J. Pan, S. Patil, K. Goldberg, and P. Abbeel, "Motion planning with sequential convex optimization and convex collision checking," The International Journal of Robotics Research, vol. 33, no. 9, pp. 1251–1270, 2014.