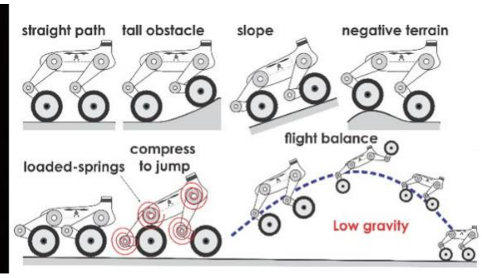
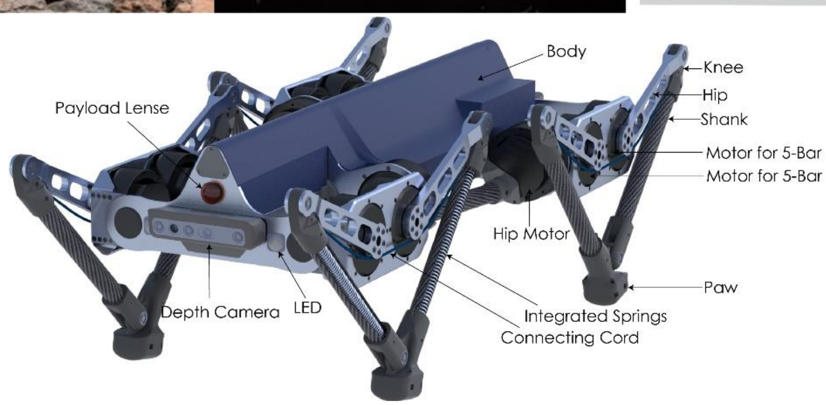
Jumping and in-flight-stabilization of a Jumping Quadruped in Mars Gravity Using Reinforcement Learning

Abstract: Over the last decade, satellites, telescopes, landers, and wheeled rovers have been the main form of space exploration. As the field of legged robotics has developed and matured significantly in recent years, we now see the opportunity to explore more diverse and interesting terrain in space using specialized quadruped robots optimized for challenging off-world planetary environments, such as craters, caves, and lava tubes. Legged robots, such as the Boston Dynamics Spot and the ANYbotics ANYmal, present a set of advantages in mobility and versatility in complex environments over traditional wheeled robots and rovers. Jumping legged robots may be able to traverse the geometrically complex subterranean voids of lava tubes on planets such as Mars. A jumping legged robot for Martian surface and lava tube exploration will retain the key advantages of quadruped systems in overcoming rough terrain, while also being able to coordinate its actuators and exploit the low gravity environment of Mars and compliant leg designs to jump for significant height and thus overcome large obstacles. This project thesis aims to contribute to the modeling, control, and simulation of jumping legged robot that is currently being built and tested by our team at NTNU. The main goal of the project thesis is to study and develop reinforcement learning techniques to enable the robot to perform mid-air stabilization using its legs. The second objective is to incorporate jumping and landing safely into this control policy. If progress is sufficient, deployment of the developed control policy to an actual legged robot may be possible. This continues work of previous master students with similar topic.





Tasks:

- Study and understand the basic Reinforcement Learning problem formulation, terminologies, and common methods.
- Study and understand the work on the split task of reorientation and jumping.
- Setup the simulation environment with simulated gravity and simplified robot.
- Use the exiting robot design to create a simplified model and start setting up the learning pipeline.
- Train the control policy and evaluate/improve the performance in simulation environment.
- Implement the control policy on a real robot.
- Strech goal is a combined policy for walking, jumping and in-flight-stabilization.

Literature (indicative):

[1] Work done by previous students on this project: https://olympus-rl.github.io/

[2] Jørgen Anker Olsen and Kostas Alexis. "Design and Experimental Verification of a Jumping Legged Robot for Martian Lava Tube Exploration." arXiv e-prints (2023): arXiv-2311.

[3] Jørgen Anker OLsen and Kostas Alexis. "Martian Lava Tube Exploration Using Jumping Legged Robots: A Concept Study." arXiv preprint arXiv:2310.14876 (2023).

[4] Westre, Andreas. *Attitude Control and Implementation of a 'Flying'Quadruped Robot*. MS thesis. NTNU, 2023.

[5] Rudin, N., Hoeller, D., Reist, P., & Hutter, M. (2022, January). Learning to walk in minutes using massively parallel deep reinforcement learning. In Conference on Robot Learning (pp. 91-100). PMLR.

[6] Borgen, Kristian Novsett. Trajectory Optimization for Optimal Jumping of Quadrupeds in Low-Gravity Environments. MS thesis. NTNU, 2023.

[7] M. Hutter et al., "Anymal-a highly mobile and dynamic quadrupedal robot," in 2016 IEEE/RSJ international conference on intelligent robots and systems (IROS), 2016: IEEE, pp. 38-44. Bloesch, M., Omari, S., Hutter, M. and Siegwart, R., 2015, September. Robust visual inertial odometry using a direct EKF-based approach. In 2015 IEEE/RSJ international conference on intelligent robots and systems (IROS) (pp. 298-304). IEEE.

[8] N. Rudin, H. Kolvenbach, V. Tsounis, and M. Hutter, "Cat-Like Jumping and Landing of Legged Robots in Low Gravity Using Deep Reinforcement Learning," IEEE Transactions on Robotics, 2021. Scaramuzza, D. and Fraundorfer, F., 2011. Visual odometry [tutorial]. IEEE robotics & automation magazine, 18(4), pp.80-92.

[9] A. W. Daga et al., "Lunar and martian lava tube exploration as part of an overall scientific survey," in Annual Meeting of the Lunar Exploration Analysis Group, 2009, vol. 1515, p. 15.

[10] M. Hutter et al., "ANYmal - toward legged robots for harsh environments," Advanced Robotics, vol. 31, no. 17, pp. 918-931, 2017, doi: 10.1080/01691864.2017.1378591.

[11] P. Arm et al., "SpaceBok: A Dynamic Legged Robot for Space Exploration," 2019: IEEE, doi: 10.1109/icra.2019.8794136.

[12] M. Kulkarni et al., "Autonomous Teamed Exploration of Subterranean Environments using Legged and Aerial Robots," arXiv pre-print server, 2021-11-11 2021.

[13] Chadwick, Michael & Kolvenbach, Hendrik & Dubois, Fabio & Lau, Hong & Hutter, Marco. (2020). Vitruvio: An Open-Source Leg Design Optimization Toolbox for Walking Robots. IEEE Robotics and Automation Letters. PP. 1-1. 10.1109/LRA.2020.3013913.

[14] Relevant project: https://www.spacehopper.ethz.ch/

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