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Terrain Adaptive Gait Transitioning for a Quadruped Robot using Model Predictive Control

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Session 3(B): Control Engineering

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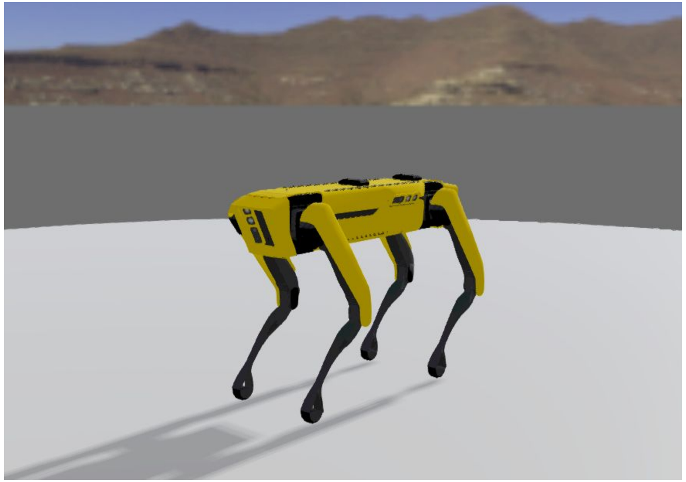
Introduction

- The advantage of legged robots:
  - High agility and high-speed locomotion
  - High stability for all kinds of terrains
  - Less surface coverage
- Applications like rescue, inspection, and exploration.
- This work mainly focuses on the stability of quadruped robots on challenging terrains with incline slopes



Literature Survey

- Literature shows that increase in flexibility leads to more vibrations and instability
- Tomislav Horvat et al. described the MPC for the quadruped robot locomotion. MPC is used to control and adjust the positions of the footsteps in order to satisfy stability constraints.
- Mahdi Khorram et al. presented the path planning of a robot on uneven terrain using LQR control for achieving stability along with ZMP stabilisation
- Jiaxin Guo et al. proposed an MPC design for foot placement and planning of the Quadruped Robot

Model Predictive Control (MPC)

- Uses the system dynamics, for predicting future steps based on the model's current state.
- A Cost function or a Quadratic Program(QP) which needs to be optimised.
- Considers the system constraints
- Better candidate for complex systems like legged robots
- Single QP required instead of multiple SISO controllers

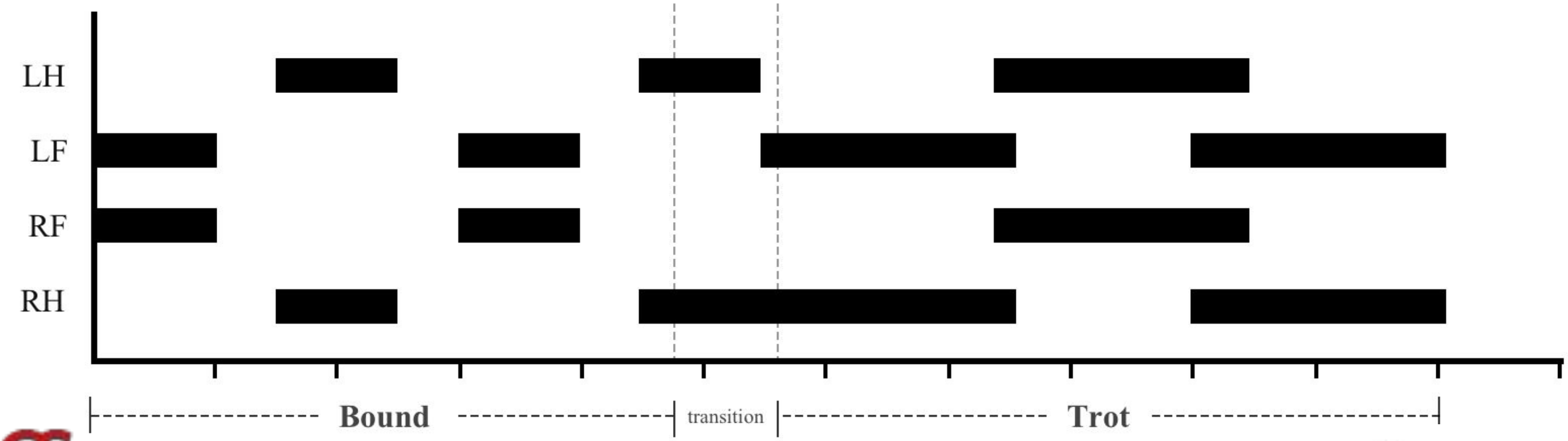
Methodology

- Workflow:
  - Lagrange-Euler dynamics formulation governing the robot’s motion
  - Design the bounding and trotting gait patterns
  - Design the force based Model Predictive Control
  - Simulate the controller in Webots environment
- State-of-the-art: Existing literature focuses on position based control which is not suitable for uneven terrains and environments with large disturbances. In our paper we present a torque based feedback control and prove that it solves these issues.

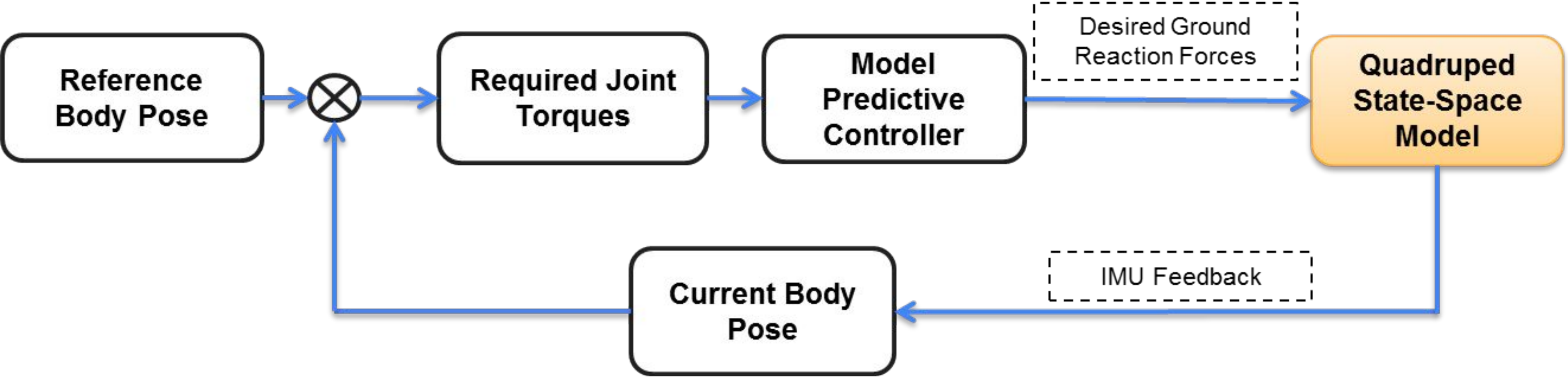
Gait definition

Bounding gait = [LF,RF], [LH,RH], [LF,RF], [LH,RH], … (High paced locomotion)

Trotting gait = [RH, LF], [RF, LH], [RH, LF], [RF, LH], ... (Medium paced locomotion)



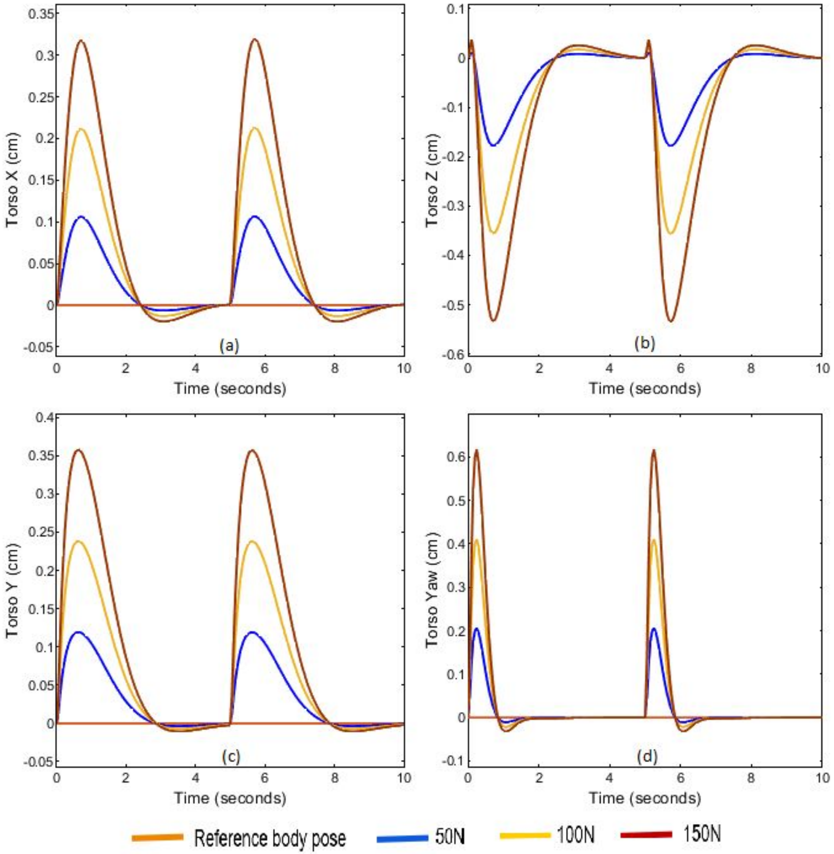
The System Architecture



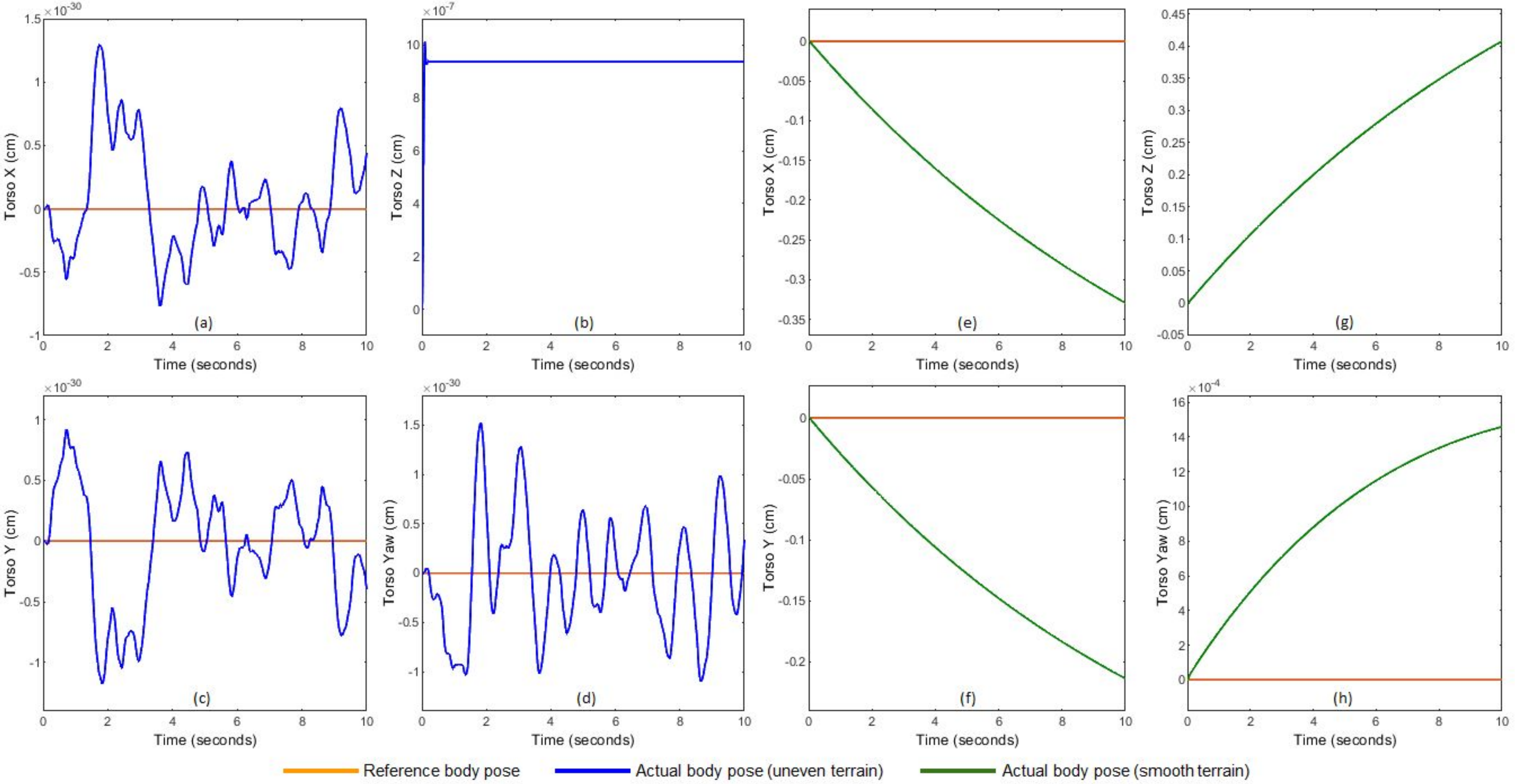
Pose Correction for Increasing Perturbations

The Robot is subjected to external impulse forces of magnitudes:

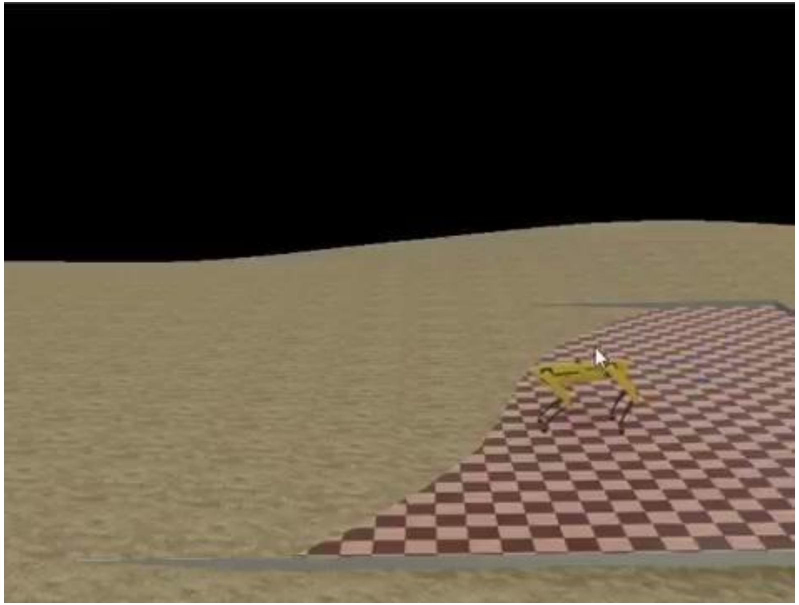
1. 50N
2. 100N
3. 150N



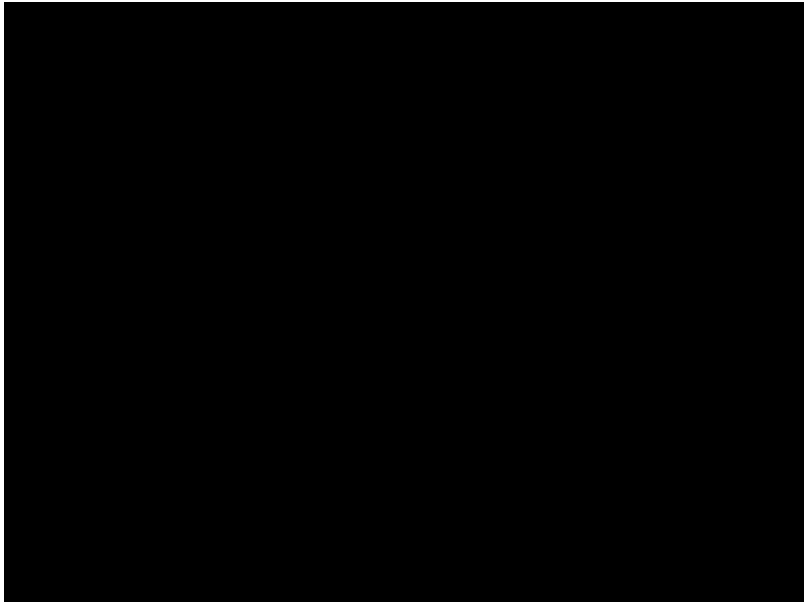
MPC design: Uneven terrain vs Smooth terrain



Simulations



Gait transition



Fall handling & force resistance

Conclusion

- All the simulations are carried out in MATLAB and Webots
- A smooth velocity based gait transition is achieved.
- Simulations show that the robot with MPC can:
  - Handle perturbations up to 150 N
  - Sustain falls from heights up to 80 cm.
- The robot is also able to traverse on inclined uneven surfaces upto 20° slope

Future Scope

- Design the other quadrupedal gaits and transitions between them.
- Design policies for the robot to achieve stable locomotion on greater inclined surfaces.
- Environment mapping will be explored for dynamic trajectory optimisation on the run.
- Design non-periodic gaits to allow locomotion through rocky and sandy terrain using Reinforcement Learning techniques.

References

[1] J. Di Carlo, P. M. Wensing, B. Katz, G. Bledt and S. Kim, ”Dynamic Locomotion in the MIT Cheetah 3 Through Convex Model-Predictive Control,” 2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2018, pp. 1-9

[2] R. Grandia, F. Farshidian, R. Ranftl and M. Hutter, ”Feedback MPC for Torque-Controlled Legged Robots,” 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2019, pp. 4730- 4737

[3] M. Khorram and S. A. A. Moosavian, ”Optimal and stable gait planning of a quadruped robot for trotting over uneven terrains,” 2015 3rd RSI International Conference on Robotics and Mechatronics (ICROM), Tehran, 2015, pp. 121-126

[4] J. Guo, Y. Zheng, D. Qu, R. Song and Y. Li, ”An algorithm of foot end trajectory tracking control for quadruped robot based on model predictive control,” 2019 IEEE International Conference on Robotics and Biomimetics (ROBIO), Dali, China, 2019, pp. 828-833

[5] T. Horvat, K. Melo and A. J. Ijspeert, ”Model predictive control based framework for CoM control of a quadruped robot,” 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Vancouver, BC, 2017, pp. 3372-3378

[6] M. Neunert et al., ”Whole-Body Nonlinear Model Predictive Control Through Contacts for Quadrupeds,” in IEEE Robotics and Automation Letters, vol. 3, no. 3, pp. 1458-1465

References

[7] P. Saraf and R. N. Ponnalagu, ”Modeling and Simulation of a Point to Point Spherical Articulated Manipulator Using Optimal Control,” 2021 7th International Conference on Automation, Robotics and Applications (ICARA), 2021, pp. 152-156

[8] P. Saraf, M. Gupta and A. M. Parimi, ”A Comparative Study Between a Classical and Optimal Controller for a Quadrotor,” 2020 IEEE 17th India Council International Conference (INDICON), 2020, pp. 1-6

[9] R. Vasconcelos et al., ”Active stabilization of a stiff quadruped robot using local feedback,” 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Vancouver, BC, 2017, pp. 4903- 4910.

[10] A. W. Winkler, C. Mastalli, I. Havoutis, M. Focchi, D. G. Caldwell and C. Semini, ”Planning and execution of dynamic whole-body locomotion for a hydraulic quadruped on challenging terrain,” 2015 IEEE International Conference on Robotics and Automation (ICRA), Seattle, WA, 2015, pp. 5148-5154.

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