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

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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.
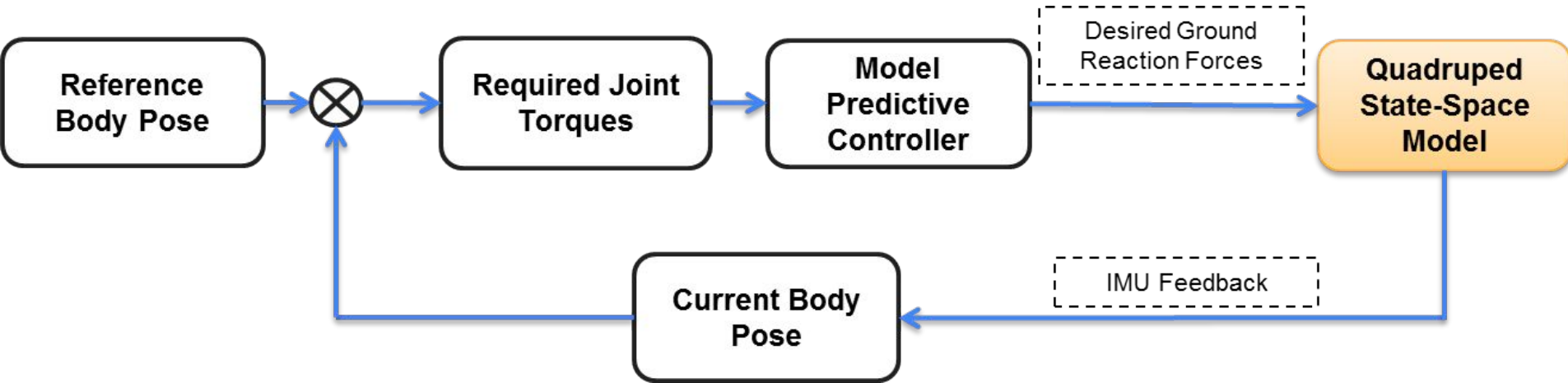
Gait definition

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

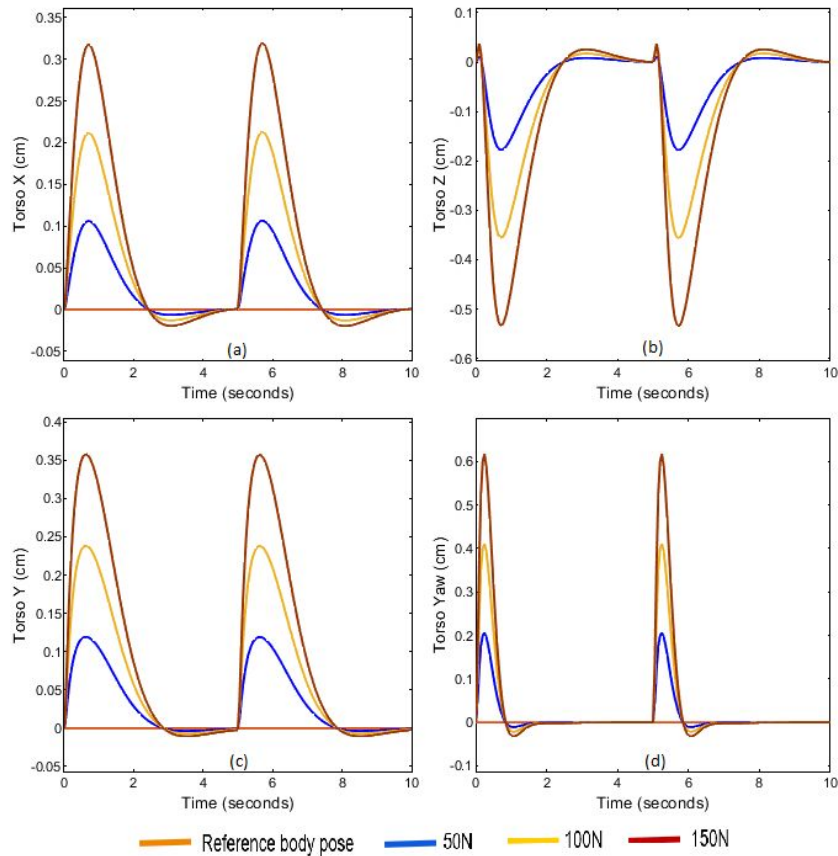Trotting gait = [RH, LF], [RF, LH], [RH, LF], [RF, LH], ... (Medium paced locomotion)
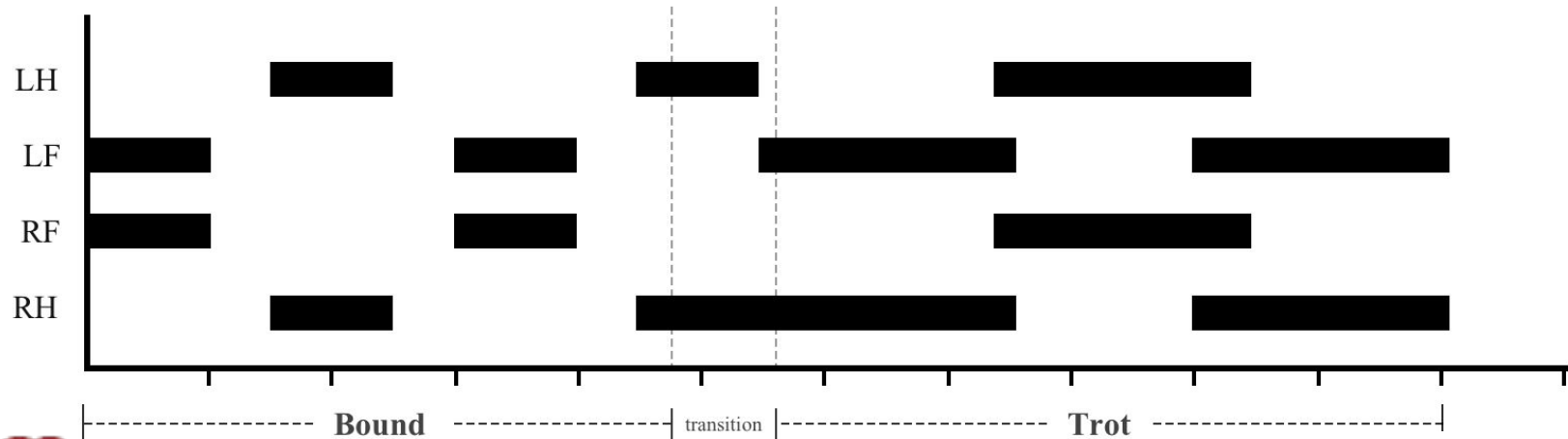
The System Architecture

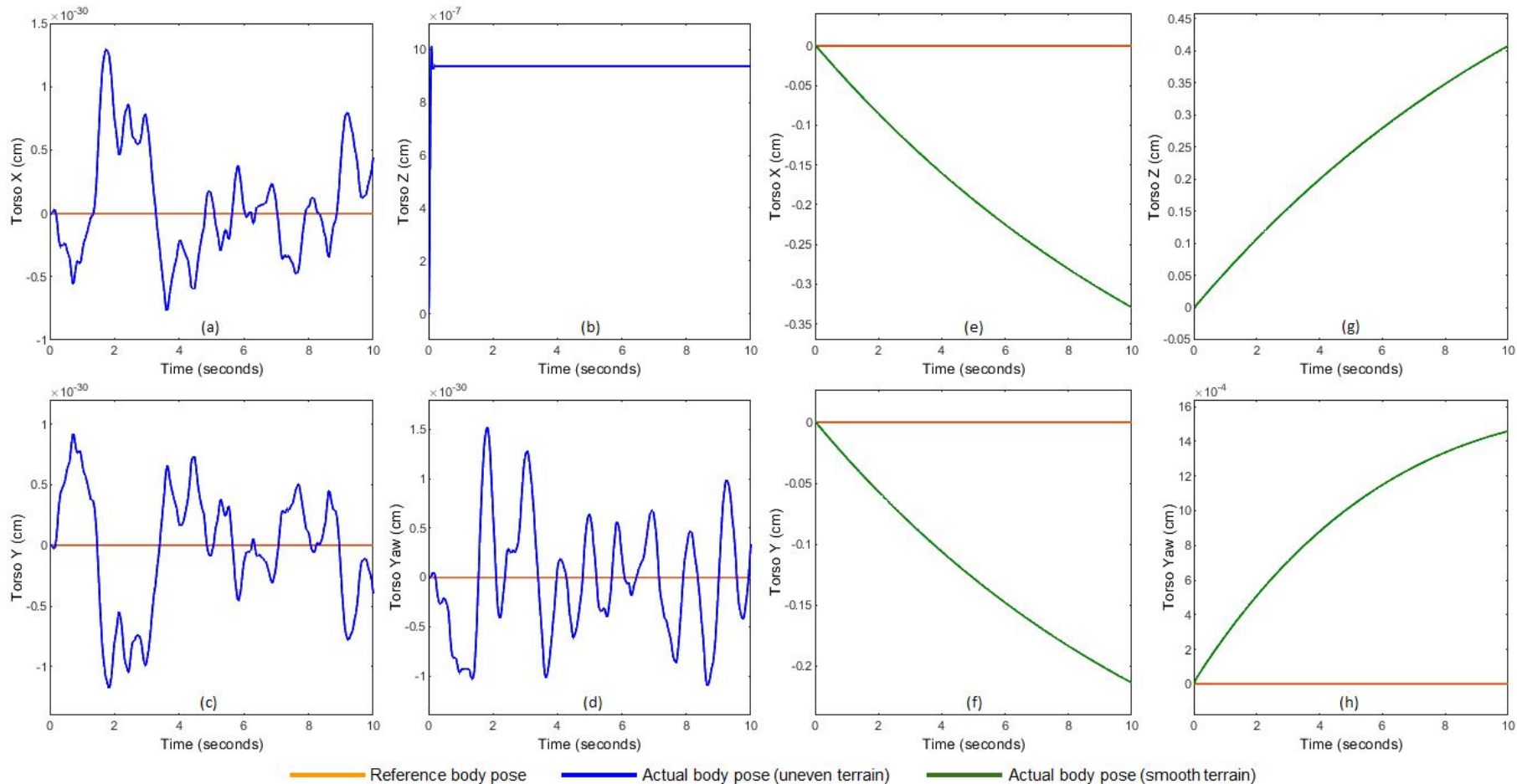# Pose Correction for Increasing Perturbations

The Robot is subjected to external impulse forces of magnitudes:
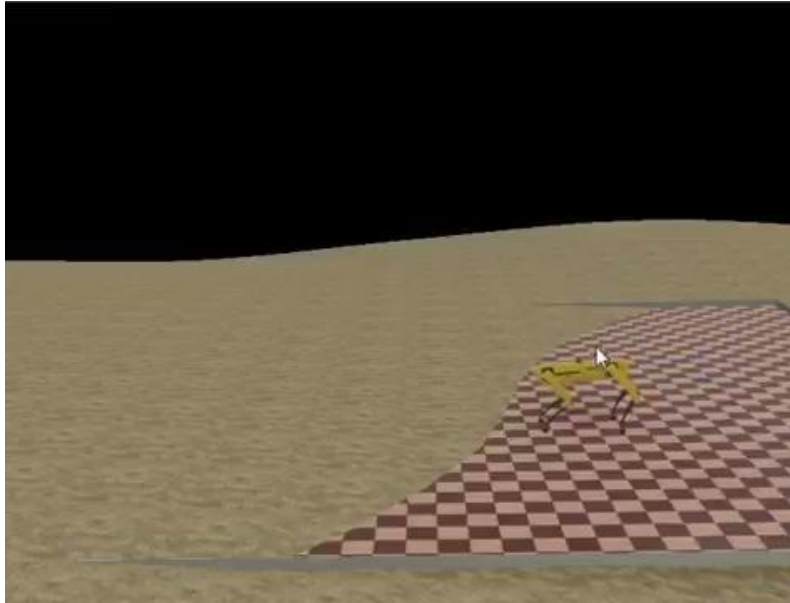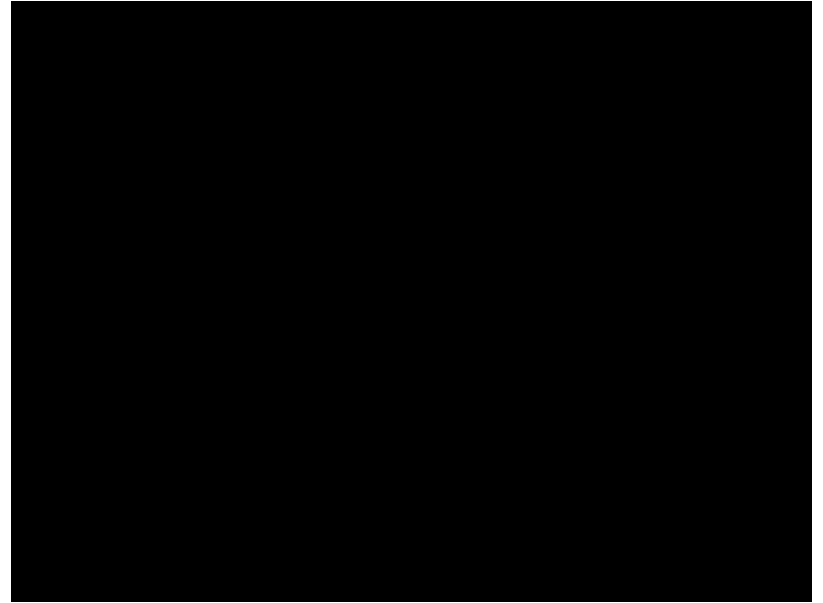
1. 50N
2. 100N
3. 150N

MPC design: Uneven terrain vs Smooth terrain

Reference body pose   Actual body pose (uneven terrain)   Actual body pose (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.

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Thank You!