Toward Robust Stair Climbing of the Quadruped using Proprioceptive Sensing

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Summary

This work addresses the robustness of robot stair climbing using the Minitaur quadruped. Our approach combines leg observers for obstacle detection with reactive behavior algorithms.

Figure 1: Minitaur robot on the stairs in Hamerschlag Hall, CMU

Motivation

- Most of the existing stair climbing solutions for legged robots assume that the stairs are in regular shapes and free of obstacles.

Figure 2: Outdoor stairs at Schenley Park, Pittsburgh, PA

- Meanwhile, outdoor stairs are much more rugged, and they may be littered with **obstacles**.
- This requires the robot to **detect** the obstacles and **react** quickly to prevent locomotive failure.
- Each of the legs on Minitaur is lightweight and driven by two brushless DC motor with no gearbox. This direct-drive design results in high mechanical transparency, which enables high leg acceleration and contact impulse detection in minimal delay.

Proprioceptive Sensing

Leg Dynamics

$$M(\theta)\ddot{\theta} + C(\theta, \dot{\theta})\dot{\theta} + N(\theta, \dot{\theta}) = \tau$$

- Each of the four linkages on a leg is treated as individual masses.
- The torque, τ, is determined with the ideal motor model and the proportional-derivative (PD) controller.
- Nelder-Mead method was applied to estimate selected model parameters.

Offline Simulation

- Due to onboard computation limit, we simulated the motion of the leg in a triangular trajectory in Matlab offline.
- The results are compared to the actual achieved leg states to form the observer residuals.

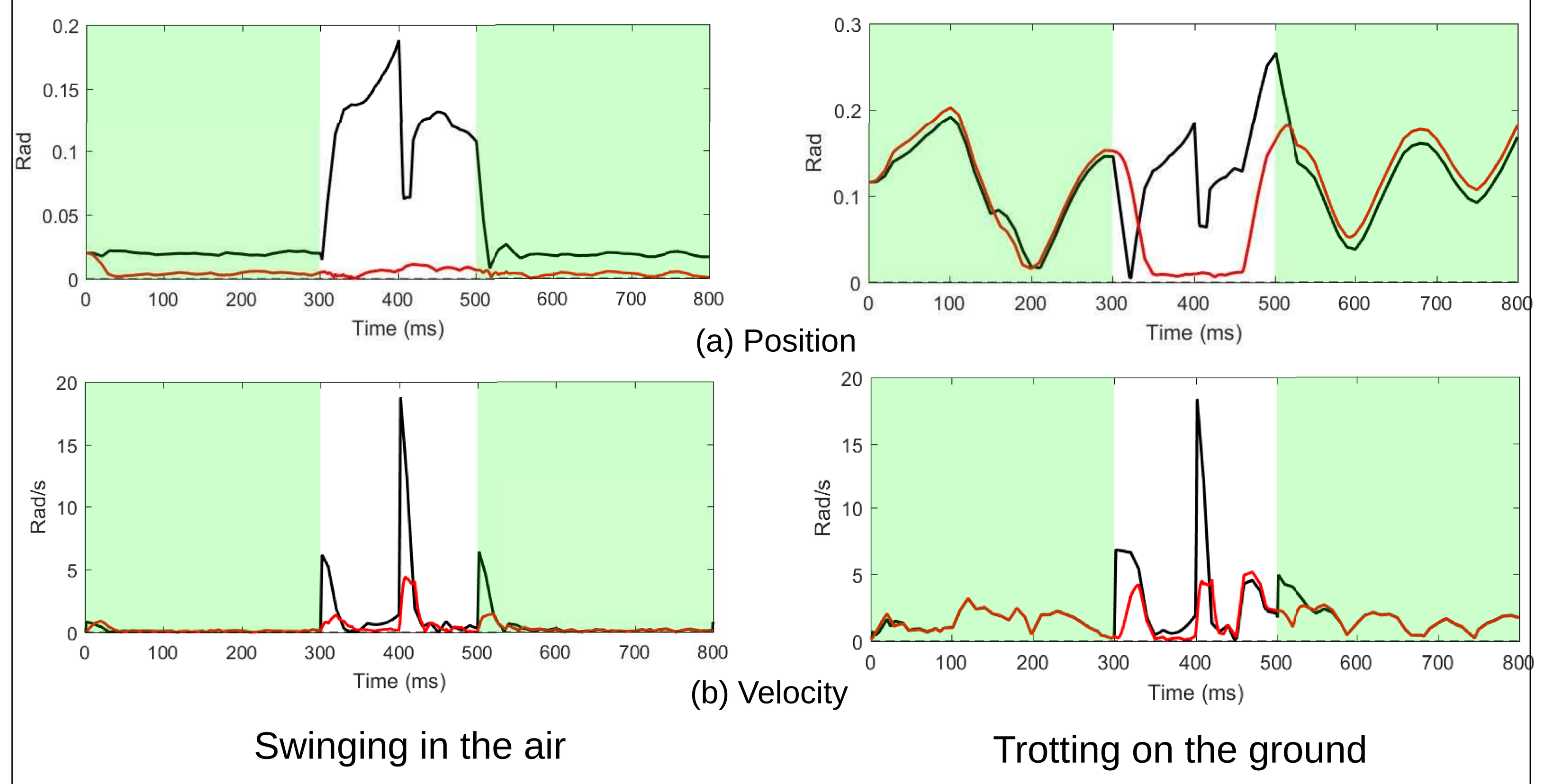

Figure 3: Observer position and velocity residuals (red) vs. PD controller tracking errors (black). Green regions are the expected stance phases.

- The observer residuals are much lower than the tracking errors during the flight phases.
- If the leg hits the stair in the air, the observer residual increases and signals the start of stair climbing.

Online Observer

- Stair Climbing involves sequenced maneuvers and open-loop control, causing offline simulation residuals to accumulate.
- An online, memoryless observer is thus necessary.
- A reduced dynamics model is adopted to maximize computation speed.

Stair Climbing Behavior

- Given the geometry limit of the legs and stairs, the robot is incapable of walking up the stairs quasi-statically.
- We developed a stair climbing behavior that incorporates a few sequenced, dynamic maneuvers.
  - Trotting towards the stair and detect it.
  - Front and rear legs bound upwards alternatively.
  - Disturbance recovery by fast leg circulation.
  - Trotting on the stair to self-align.

Figure 4: High-speed image sequence of the rear legs bounding upwards in 0.5 second.

Results

- The robot was able to detect the stair and ground obstacle consistently as it trotted from different distances.
- Currently In Progress
  - Detecting obstacles on the stairs
  - Robust stair climbing

Future Work

- Develop a stair climbing behavioral model with force control.
- Install an inertial or aerodynamics tail to improve stability and dynamic maneuverability.
- Add extra onboard computer for online, full dynamics disturbance detection and contact force sensing.
- Use motor current sensing to skirt the ideal motor model.

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