Bounding, jumping, turning and stopping with a small, low-cost quadrupedal robot

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1 Motivation

In pursuit of a general framework for robot locomotion planning and control, we seek an inexpensive and iterable platform for dynamic legged locomotion that can mix force, position, and impedance control techniques. With this hardware we seek to develop and study a variety of locomotion tasks, focusing on controllers that exploit the best features of force and impedance control, respectively.

2 State of the Art

Locomotion controllers often rely on accurate force or impedance, but accurate control remains a significant challenge for real-robots. Many limbs use actuators with high-intrinsic inertia which compromise control fidelity, particularly during foot-ground impact. Techniques such as endpoint force sensing, inverse dynamics and series elasticity can enhance dynamic performance during mechanical interaction, but these methods involve time consuming system identification or hardware iteration which can be expensive and time consuming.

"Direct-drive" robots use low gear transmission ratios, current controlled DC motors, and rigid limb links [1]. These limbs can greatly simplify implementation and experimentation by enabling the control of force and a wide range of limb impedances with minimal computational complexity. Generating sufficient torque density is challenging for mobile robots, and the MIT Cheetah is the only well-known robot which extends this paradigm to perform power-autonomous dynamic locomotion [2], though its custom drive system limits the replicability of the platform at present.

3 Approach

We extend the direct-drive paradigm to a new robot limb which uses commercial-off-the-shelf components and rapid manufacturing methods. The robot limb is easily replicable and iterable, resulting in a lightweight and inexpensive platform which can be used for aggressive-maneuver experiments.

A robot limb that can execute arbitrary force commands and limb impedance through computer control opens a wide design space for planning through the marriage of concise force trajectory planning and the dynamic stabilization properties of impedance control. Building on simulation-only studies of broad locomotion capabilities [3], we are developing a library of open-loop gait behaviors that use simple building blocks such as parameterized force and impedance trajectories organized with simple event-driven rules.

4 Current Results

We present the Super Mini Cheetah (SMC) robot, a small (9kg) iterable power-autonomous quadruped. The robot can perform a variety of dynamically-stabilizing gaits — bounding, jumping, turning, stopping, as well as walking with only three functional limbs — using simple force and impedance control of each leg and simple state machines to organize footfalls. Stable forward speed is modest, 1.2 m/s, or about 4 body-lengths/s, but the jumping height, bounding duty cycle and motor current duty cycle demonstrate that higher speeds are physically possible. To the best of our knowledge, this is the first small (sub-10kg), power autonomous robot to demonstrate such a wide range of ballistic locomotion behaviors.

5 Best Possible Outcome

The SMC robot shows the potential for dynamic legged locomotion using rapid prototyping methods, which allows for faster experimentation and the potential for replicable hardware to be shared between research labs. In particular, we show the usefulness of a leg that can mix force, position, and impedance control by demonstrating the wide range of behaviors that can be achieved using intentionally simple force and impedance trajectories.

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References

[1] Asada, H et al. "Direct-drive robots...", MIT 1987.
[2] Park, H et al. "Quadruped Bounding...", IROS 2014.
[3] Coros, S, et al. "Locomotion skills...", ACM, 2011.

Preferred presentation: poster session

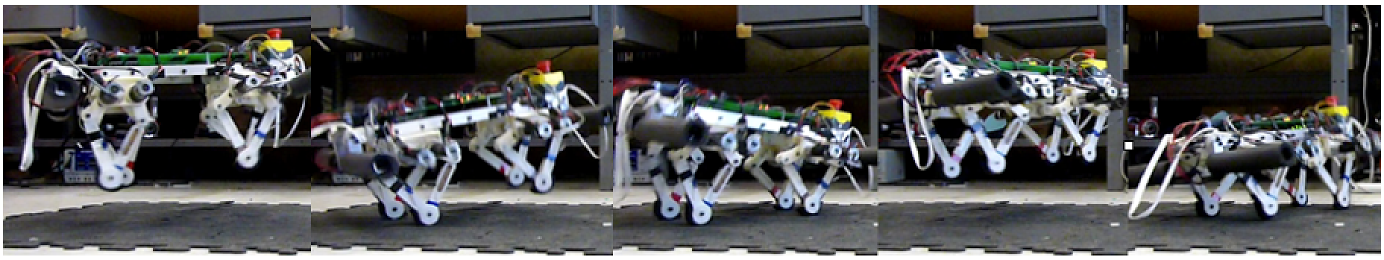

Figure 1: The Super Mini Cheetah (SMC) quadrupedal robot: a small (9kg) iterable robot capable of bounding, turning, stopping, as well as walking with only three functional limbs. The robot is shown turning at $\frac{\pi}{3}$ rad/s. This time-lapse image is taken at intervals of 0.167 s.