Impulse-Based Gait Design and Control for Variable Speed Galloping on MIT Cheetah Robot

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1. Motivation

In this research, we seek to design an impulse-based controller for galloping of the MIT Cheetah Robot.

2. State of the Art

Galloping is known to be the most preferred gait in high speed in quadrupedal mammals [1]. Many quadruped robots have been developed and studied so far, but only a few robots have achieved a high-speed gallop gait successfully. Palmer et al. [2] presented a controller implemented in their simulation engine, which results in stable 3D galloping at 4.15 m/sec on a flat ground. Boston Dynamics presented 12.6m/s galloping of a 2D tethered hydraulic Cheetah, but the controller design is not published.

3. Own Approach

Our approach is based on the hypotheses formed from studying galloping animals [3][4][5]: 1) ground reaction forces (GRF) are directly controlled for vertical momentum balance, 2) a finite state machine comprising four phases are controlled by state-based events, and 3) the swing phase is governed by a time-based trajectory control. Fig. 1 summarizes our control approach. An 11-DOF cheetah model with non-trivial inertia legs and semi-active spine [6] is derived from the MIT cheetah robot. Using the obtained model, we obtained a periodic limit cycle running by optimizing the horizontal and vertical GRF profile and gait pattern (timing and duration of four phases shown in Fig.1). The swing phase trajectories are optimized separately. To stabilize the limit cycle running, a finite state machine is constructed to manage the transitions among phases, and impedance controllers around the height and the pitch trajectories are added, along with the GRF profile obtained from the optimization. Also, the optimized GRF profiles are converted to be functions of leg-angle, resulting in state dependent feedback control, similar to [7]. Lastly, the optimized gait pattern is enforced by adjusting duration of protraction phase at every foot take-off event. The running speed is modulated by scaling vertical impulse (GRF profile), equal to the total gravitational impulse at desired speeds. Control authority on horizontal direction force is used to regulate desired speed.

4. Current Results

An open loop 3 m/sec galloping gait is obtained from the optimization with torque limits of the motors custom-designed at MIT. The stabilized controller allows the robot to stably gallop with an unexpected sudden step-down (up to 38 cm) and a step-up (up to 12.5 cm) as well as a ground with random height variations ranging 1.5 cm to 6cm. This control architecture allows for a wide range of galloping speeds varying from 3 m/s to 11.5 m/s.

5. Best Possible Outcome

Currently, this controller is the basis of a stable 3D galloping and will be implemented in the MIT cheetah robot. The design approach can be implemented to realize various gaits.

6. Reference

[1] Hoyt et al. (1981) Nature
[2] Palmer III et al. (2010) J. Intell. Robot.
[3] Daley et al. (2003) J. Exp. Biol.
[4] Walter et al. (2007) J. Exp. Biol.
[5] Maes et al. (2008) J. Exp. Biol.
[6] Seok et al. (2013) Int. Conf. Robotics and Automation
[7] Koushil et al. (2011) Int. J. Robot. Res.

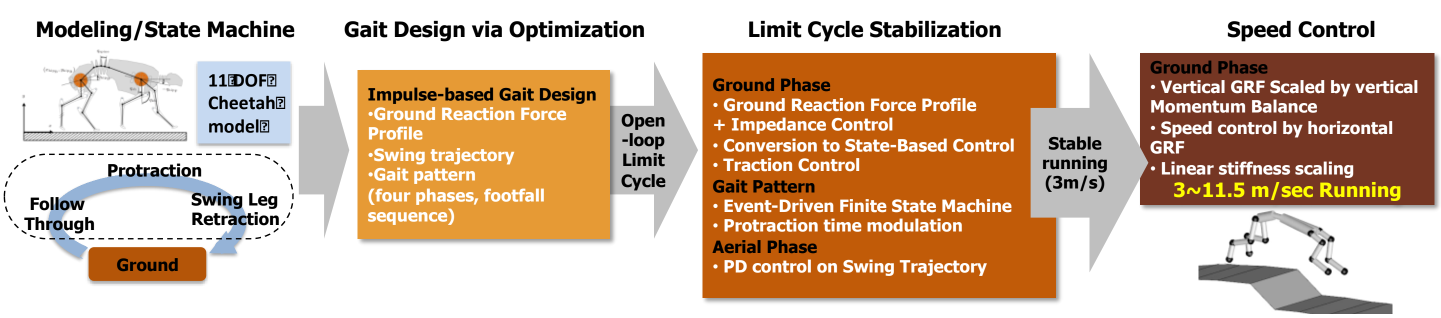

Figure 1 Impulse-based Gait and Control Design Process