Towards Modular Control for Moderately Fast Locomotion over Unperceived Rough Terrain

Mostafa Ajallooeian, Soha Pouya, Sébastien Gay, Alexandre Tuleu, Alexander Sproewitz and Auke J. Ijspeert
Biorobotics Laboratory, École Polytechnique Fédérale de Lausanne (EPFL), Switzerland. **email:** {*first.last*}@*epfl.ch*

1 Motivation

We are motivated to build simple controllers for quadruped robots to locomote over *unperceived* moderately difficult rough terrain at moderately fast speeds. The presented approach here does not need force sensing at feet, and does not need information about the mass properties of the robot like inertia tensors, so it is apt for relatively cheap and lightweight robots. We explore our approach with two different simulated robots, one being the simulation of the Oncilla robot [1] which will soon be used for validation.

2 State of the Art

Quadrupedal locomotion over *perceived* rough terrain has properly been explored in the context of DARPA's learning locomotion program. However there are not many control approaches which address locomotion over *unperceived* rough terrain. Examples are the Raibert's control on BigDog [2], the Central Pattern Generator (CPG) control on Tekken [3], the floating-based inverse dynamics control on LittleDog [4] and HyQ [5], and the operational space control on StarlETH [6]. Details about the BigDog are not publicly disclosed, the CPG control on Tekken is quite complex and is rather a work of art, the LittleDog control in [4] has been tested with slow static walking, and the rough terrain locomotion demonstration on HyQ and StarlETH are not on a continuously-rough terrain (occasional obstacles on treadmill). Nevertheless, majority of the mentioned works are advancing and going under systematic testing as we speak. We explore simple control for dynamic quadrupedal locomotion with moderately high speeds ($\approx 2BL/s$) over continuously-rough terrain. The results here are limited to our systematic tests in simulation, and the first preparations to test our approach on the Oncilla hardware robot.

3 Methodology

Our control methodology consists of modules which contribute to different elements in locomotion: 1) Coupled low-dimensional nonlinear oscillators encoding desired joint trajectories in stable dynamical systems. The asymptotic stability of the limit cycle of these oscillators facilitates the process of feedback integration; 2) Fast reflexes to compensate for unpredicted events including missing a contact or stumbling after a leg hits an obstacle in the swing phase. These reflexes are added as feedback signals to the oscillator module; and 3) Model-based posture control mechanisms to correct unwanted body rotations (roll and pitch for balance and yaw for direction). Two examples of such controllers are depicted in Figure 1. The approach in the top corrects the torques generated by the coupled oscillators with posture control torques (generated using Virtual Model Control [7] and leg-based J^T), while in the approach depicted in the bottom, the posture controller produces feedback signals (using task-space velocity control and leg-based J^{-1}) which affect the states of the oscillator module.

4 Results

We systematically tested our modular controllers on two simulated robots (both having cat-like sizes and weights and low-inertia legs) on a variety of unperceived rough terrains (rocky setup, uneven terrain with $8-12\%$ of leg length variations, slopes up to 20% and external pushes up to $15[N], 0.5[s]$). The approach in Figure 1-top was tested on a mechanically stiff quadruped with two segmented legs [8], and the approach in Figure 1-bottom was tested on the Oncilla simulated robot, which has compliant three segmented pantograph legs. For both, 80%+ success rates where obtained (avg. over 25 different runs, videos in `http://biorob.epfl.ch/page-89661-en.html`). The hardware experiments are now under progress. As of this moment, the Oncilla robot locomotes with the coupled oscillators, and we are integrating it with a high-end IMU sensor for absolute rotation sensing, and will validate our control approach on the hardware robot in near future (initial results to be ready for the meeting).

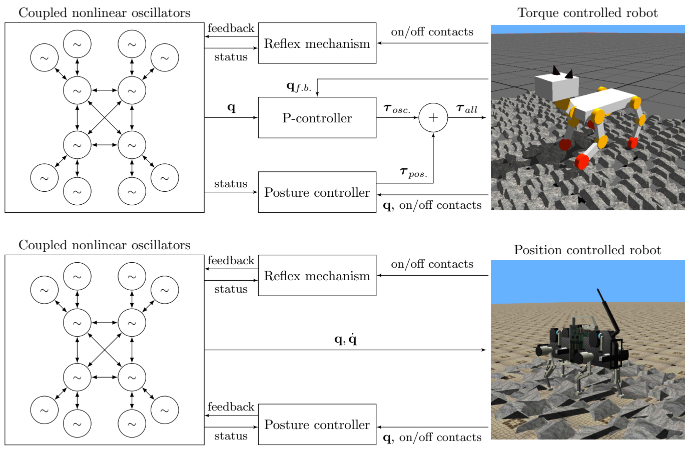

Figure 1: Control strategies. Top) Torque control strategy. Bottom) Position control strategy. $\mathbf{q}$ and $\boldsymbol{\tau}$ are the joint angles and torques respectively.

5 Discussion

The introduced control methodology is powerful in situations where additional sensing/information of ground reaction forces and mass properties are not available, or the computational resources are limited. We have used a P-controller to convert oscillator outputs to joint torques (Figure 1), but one can instead utilize floating-based inverse dynamics if a torque controlled robot, sufficient computational resources, GRF sensing and mass properties are available/known. Since the introduced approach is apt for *unperceived* rough terrain locomotion, it can be a control basis to add additional exteroception feedback (e.g. vision) to improve the performance. This can possibly cover cases like rougher terrains where e.g. foothold planning is needed.

Acknowledgement
The research leading to these results has received funding from the European Community's Seventh Framework Programme FP7/2007 - 2013 - Challenge 2 - Cognitive Systems, Interaction, Robotics - under grant agreement No. 248311 (AMARSi).

References

[1] Sproewitz et al. (2011) AMAM.
[2] Raibert et al. (2008) 17th IFAC World Congress.
[3] Fukuoka et al. (2003) IJRR.
[4] Buchli et al. (2009) IROS.
[5] Semini et al. (2011) IMechE, Part I: JSCE.
[6] Hutter et al. (2012) RSS.
[7] Pratt et al. (2001) IJRR.
[8] Ajallooeian et al. (2013) ICRA.