Motor Control Adaptation to Changes in Robot Body Dynamics for a Complaint Quadruped Robot

Soha Pouya, Peter Eckert, Alexander Sproewitz, Rico Moeckel,
and Auke Ijspeert

Biorobotics Laboratory, Ecole Polytechnique Federale de Lausanne (EPFL),
Lausanne, Switzerland
`first_name.last_name@epfl.ch`
`http://biorob.epfl.ch`

Abstract. One of the major deficiencies of current robots in comparison to living beings is the ability to adapt to new conditions either resulting from environmental changes or their own dynamics. In this work we focus on situations where the robot experiences involuntary changes in its body particularly in its limbs' inertia. Inspired from its biological counterparts we are interested in enabling the robot to adapt its motor control to the new system dynamics. To reach this goal, we propose two different control strategies and compare their performance when handling these modifications. Our results show substantial improvements in adaptivity to body changes when the robot is aware of its new dynamics and can exploit this knowledge in synthesising new motor control.

Keywords: Legged Robots, Locomotion Control, Adaptive Behavior.

1 Introduction

The topic of robot legged locomotion continues to flourish and develop, yet several challenges are present in designing, modelling and control of such robots. While the mechanical design defines the limits of robot capabilities, the locomotion performance can also be influenced largely with the selected control technique. For instance decentralised joint space control approaches may suffice for statically stable robot motions. In such cases, system dynamics is preserved and play only a minor role. When dealing with body changes, one can not ignore the strong influence of the system dynamics on the performance. These influences can be partially seen and treated as disturbances (via decentralised PD controllers). On the other hand a more proper and systematic way -instead of reducing the effects- is to adapt the system by incorporating leg dynamics when designing the control laws [1]. Having this objective in mind, we provide control laws benefitting from model-based feedforward prediction terms to adapt to new robot dynamics. By adding this term to the PD position controllers at each joint we decrease the reliance of the robot's control to its feedback terms. We show

N.F. Lepora et al. (Eds.): Living Machines 2013, LNAI 8064, pp. 434–437, 2013.

that our proposed control scheme not only helps the robot to perform with more compliant behavior, but also provides higher robustness against changes e.g. in the inertial properties.

2 Methods

We use the biologically inspired Cheetah-cub quadruped robot (Fig-1-c) designed at EPFL/Biorob [2] and develop its rigid body dynamics (RBD) model (Fig-1-d) based on articulated-body algorithm [3] by using the simulation and control software package SL [4]. The model is carefully tuned to match the real robot for both its geometrical and inertial properties. The overall control-learning architecture is represented in Fig-1 (a and b). Through an optimization process for the robot's speed applied at its joint position control profiles, we extract a locally optimized gait as the nominal solution. These profiles are generated via a central pattern generator (CPG) based controller [5] which facilitates the generation of different gait types through the coupling terms between different degrees of freedom. The CPG-based controller is well-suited for the optimization process as it encodes the control profile with only a few tuning parameters. Taking the result of this process as the preferred nominal gait, we setup the control loop with two main blocks: An inverse dynamics (ID) block. It provides feedforward prediction on the required torques regarding the new system dynamics. The second, feedback controller (PD) block performs as the disturbance rejector. We make the assumption that once the inertial parameters of the system change, they can be estimated by using state of the art parameter estimation methods [6]. We then propose two different control schemes; *(i) a low gain PD + ID* controller where the updated dynamics of the system is incorporated within the control law through feedforward torques and *(ii) a high gain PD only* controller where the robot only uses decentralised PD controllers per joint with no updates from the new dynamics terms. In order to investigate the performance of each control scheme when dealing with body changes we systematically decrease the leg inertial properties (mass and moment of inertia) and compare how this affects the robot's speed and cost of transport (COT) while performing bounding gait.

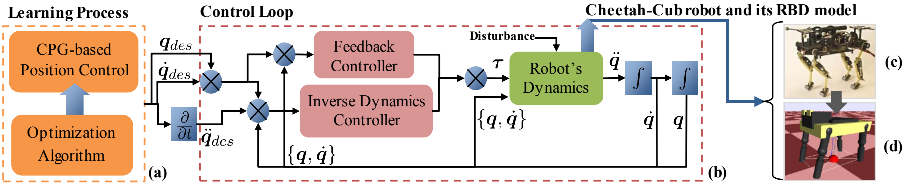

Fig. 1. The proposed control-learning architecture composed of (a) the learning process to find an opimal gait for the given robot dynamics, (b) the control loop to reproduce the optimal gait, (c) the bioinspired quadruped robot Cheetah-cub and (d) the RBD model of the robot in SL software.

3 Results and Discussion

Figure 2 shows the results of the systematically changing inertial parameters, and its effect at the robot's speed and COT, for our two proposed control schemes. We perform these experiments for four kinds of experiments: changes in the left-fore (LF) leg, the right-hind (RH) leg, both fore legs, and both hind legs. In all cases, we observed that the locomotion performance is highly sensitive to these changes when applying decentralised joint-based PD control. Results show major drops in forward velocity particularly for the case of changes in the hind legs (e.g. to less than 0.4 of nominal speed after 20% and total failure after 55% mass reduction for RH). We explain this as follows: PD gains tuned for the initial system start to lose their performance when the system inertia changes. Our proposed control scheme with an updated ID however shows several, substantial improvements; *(i)* it shows higher adaptivity to body changes, by handling up to 80% reduction for the individual legs and up to 60% for both legs. *(ii)* it increases the nominal speed due to lower PD gains and a resulting more compliant behavior. *(iii)* it results in lower COT values due to smoother torque commands in comparison to a high-gain-PD control. In order to complete this architecture, an extra module is required to learn the new dynamics. We are currently developing this module as well as transferring the results to the real robot.

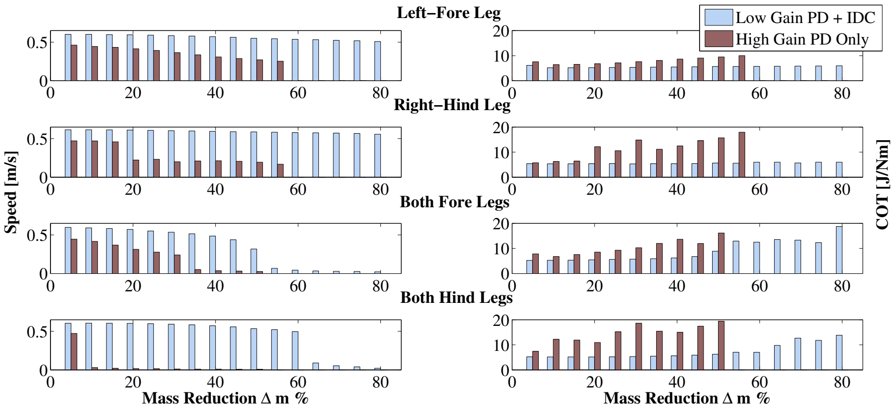

Fig. 2. The robot's speed and COT vs. the systematic change in inertial properties of (from top to down) only left-fore leg, only right-hind leg, both fore and both hind legs. For each setup the two proposed control schemes are used and compared.

Acknowledgments. This work has received funding from the European project Locomorph (grant agreements No. 231688). We gratefully thank Stefan Schaal, Mrinal Kalakrishnan and Ludovic Righetti for their help to develop 3D dynamics model of the robot in SL simulation and control package.

References

1. Siciliano, et al: Robotics Modelling, Planning and Control. Springer (2008)
2. Sproewitz, A., et al.: Towards Dynamic Trot Gait Locomotion Design, Control, and Experiments with Cheetah-cub, a Compliant Quadruped Robot. IJRR (2013)
3. Featherstone, R.: Rigid Body Dynamics Algorithms. Springer, Heidelberg (1987)
4. Schaal, S.: The SL simulation and real-time control software package. Technical report, University of Southern California (2009)
5. Ijspeert, A.J.: Central pattern generators for locomotion control in animals and robots: a review. Neural Networks 21 (2008)
6. Mistry, M., Schaal, S., Yamane, K.: Inertial parameter estimation of floating-base humanoid systems using partial force sensing. In: Humanoid Conference (2009)