Optimization-Based Full Body Control For The DARPA Robotics Challenge

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***Abstract*—We describe our full body humanoid control approach developed for the simulation phase of the DARPA Robotics Challenge (DRC), and the modifications made for the DRC Trials. We worked with the Boston Dynamics Atlas robot, which has 28 hydraulic actuators. Our approach was initially targeted at walking, and consisted of two levels of optimization, a high level trajectory optimizer that reasons about center of mass and swing foot trajectories, and a low level controller that tracks those trajectories by solving floating base full body inverse dynamics using quadratic programming. This controller is capable of walking on rough terrain, and also achieves long foot steps, fast walking speeds, and heel-strike and toe-off in simulation. During development of these and other whole body tasks on the physical robot, we introduced an additional optimization component in the low level controller, an inverse kinematics controller. Modeling and torque measurement errors and hardware features of the Atlas robot led us to this three part approach, which was applied to three tasks in the DRC Trials.**

I. Introduction

Originally targeted at rough terrain bipedal walking, we developed a walking control approach that can achieve a sequence of footstep targets, as well as walk fast on level ground [1]. The controller consists of two levels. The high level controller performs online trajectory optimization with a simplified model that only reasons about the center of mass (CoM) of the robot. The low level controller was originally designed to use inverse dynamics (ID) alone, and we added an inverse kinematics (IK) component to cope with modeling error when controlling the physical robot. For the DRC Trials we redesigned the high level controller to also handle ladder climbing and full body manipulation. Figure 1 shows a diagram of our approach.

II. High level controller

The high level controller is application specific. For simulated walking, we optimize the CoM trajectory given a sequence of desired foot steps. The swing foot trajectory is parametrized with quintic splines. For the DRC, we implement static walking instead due to development time constraints. For ladder climbing, the CoM motion and each limb's repositioning is encoded within a state machine. For full body manipulation, we track desired end effector location while maintaining balance.

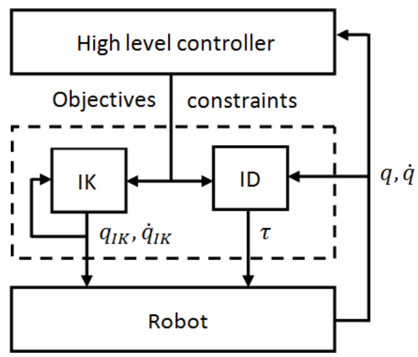

Fig. 1. The high level controller generates desired motions and constraints. Inputs to the high level controller's range from a foot step sequence to a pre-grasp pose or operator commands depending on the specific application. The low level full body controller, which is enclosed by the dashed rectangle, takes the high level objectives and robot states $(q, \dot{q})$ as inputs and outputs desired position q_{IK}, velocity $\dot{q}_{IK}$ and torque τ for each joint. Note that IK uses its own internal states rather than the measured robot states.

III. Low level controller

The low level controller generates full body motion according to the high level controller's plan while obeying various kinematic and dynamic constraints. Since the desired Cartesian motion and various constraints are all linear with respect to the unknowns, we can formulate both ID and IK as quadratic programming problems. For ID, we solve for joint and the floating base acceleration, joint torques and contact forces simultaneously. For IK, we optimize for joint and floating base velocity. Relative importance among different objectives are specified using weights. In the current implementation, IK and ID are solved independently.

IV. Results

We successfully applied the proposed controller on the Atlas robot for the terrain, ladder climbing and full body manipulation tasks during the DRC.

References

[1] S. Feng, X. Xinjilefu, W. Huang, and C. Atkeson. 3d walking based on online optimization. In *Humanoid Robots, 2013. Humanoids 2013. 8th IEEE-RAS International Conference on*, 2013.