Simultaneous Online Optimization of Kinematic and Dynamic Constraints for Stable Robot Walking

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I. Introduction

We recently released a high-performance multi-goal inverse kinematics solver (BioIK 2) [1] [2], which combines evolutionary optimization with gradient-based methods and with a novel extrapolation method for fast population-based optimization on kinematic structures. The optimization problem can be specified through user-defined cost functions, or by choosing from a comprehensive set of pre-defined IK goals, including a whole-body balancing goal, which can be used for stable bipedal walking. Since the release of our related paper [1], we added improved inverse dynamics to the balancing goal and started developing a walking controller based on our BioIK 2 solver.

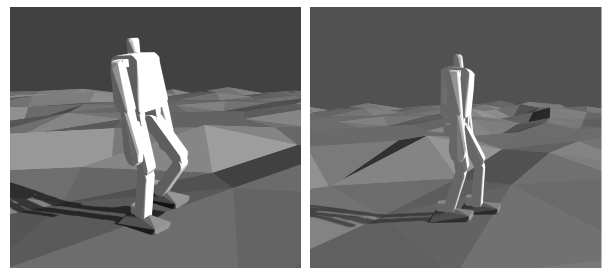

Fig. 1. Simulated robot walking on uneven terrain

II. Walking

The pose of the robot is controlled via a whole-body dynamic balancing goal, two position goals for foot placement, and orientation goals on the feet and torso. Additional goals can be added depending on the task.

The dynamic balancing goal reduces imbalances between gravitational forces, accelerational forces and torques, measured balancing errors, and a target vector.

Accelerational forces and torques are computed by combining the current solution candidate with prior joint trajectories. A variable friction term is included, which can also be used as a regularization term and to compensate inaccuracies in the dynamic model or during actuation. Forces can be computed at different granularities, from a simple inverted pendulum model to accurate force-torque estimates for all links. For slow static walking on a flat plane, the inverted pendulum model seems to be sufficient. For more complex tasks, per-link force and torque estimates usually lead to better results.

The cost function of the dynamic balancing goal computes the squared lengths of one or more force/torque vectors. For accurate dynamic balancing, all components are first transformed into a target frame, forces which are counteracted by contacts are removed, and the remaining torques are accumulated.

Balancing errors are estimated from measured joint angles, IMU measurements, and predicted positions. The estimated errors are filtered and fed back to the balancing goal, to the reflexes, and to the gait generator.

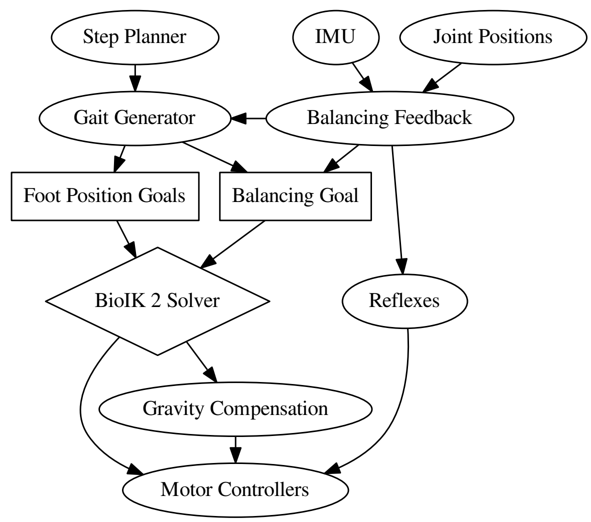

Fig. 2. Block diagram

PD joint position control is combined with additional effort control using input from inverse dynamics and from foot reflexes. To control the ankle joints, we use relatively small position control gains and mostly effort control from foot reflexes, allowing compliant motion on uneven terrain. Foot reflexes are computed from filtered balancing error estimates.

Foot positioning and the target vector of the balancing goal are controlled by a procedural gait generator, which receives step descriptions from a step planner, computes intermediate positions for the feet and for the balancing

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vector, and moves the IK goals. Foot heights are dynamically adjusted according to ground estimates which are derived from joint angle feedback to correct inaccurate step plans.

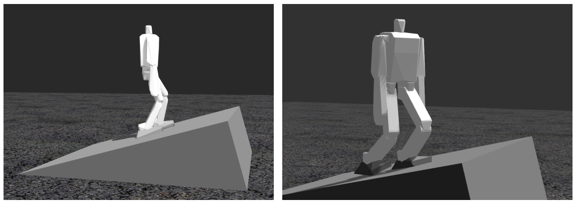

Fig. 3. Simulated robot walking up a ramp

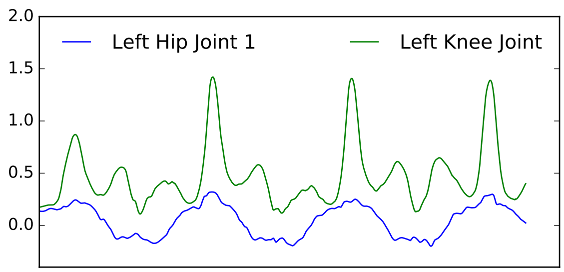

Fig. 4. Joint angles, adjusting after walking onto a ramp

III. Conclusion and Future Work

The BioIK 2 solver appears to be well suited for balanced full-body robot control and can correctly solve for kinematic as well as dynamic constraints simultaneously, providing a good starting point for developing walking controllers. In simulation, robots are able to successfully traverse different types of terrain using the described methods. While this work focused mainly on aspects related to inverse kinematics and inverse dynamics, improvements could be made to the step planner and to the gait generator. To identify areas for further improvement and to overcome the limitations of the simulation environment, we intend to test the developed methods on real robots.

References

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