Towards Agility in Compliant Point-Foot Bipeds

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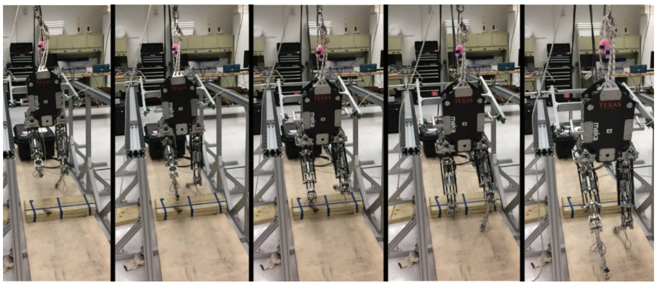

Figure 1: Preliminary Results: Three steps over obstacle.

1 Motivation

In order to be considered fully adapted to human environments, robots will inevitably be expected to reach the level of kinaesthetic competence which humans take for granted. Ultimately, this bar is very high. With only a moment of planning a human can jump over a fence, hop out of a car, or leap between stones on a hiking trail. Why not push the boundaries of robot athleticism, to maybe one day have robots live up to our high expectations as humans.

2 Hardware

Motivated by the desire to have a robot capable of walking over far from flat terrain, one which can achieve fast leg motions despite the power density limitation of electric motors, our Hume robot is a point-foot biped. At 20 Kg mass and standing 1.5 meters tall, Hume is a light-footed and quick moving robot, well suited for our task. Series elastic actuators on all of Hume's joints use springs to provide force sensing and mechanical compliance. In our current strategy, we use a relatively stiff low level controller and the series elastic actuator component is used mostly as a force sensor.

3 Preliminary Results

While Hume is yet to leave its planerization linkage, we have some interesting preliminary results. First, Hume can now walk up to three steps using a modified phase space planner[1] based on the prismatic inverted pendulum model. It does this using joint-level position controllers and planner modifications which account for the controller's limitations. See results in Fig. 1.

To overcome difficulties caused by dynamic behaviors not predicted by the simple inverted pendulum model, we introduced several modifications in the planner. Although they are ad-hoc to some degree, the planner allowed us to execute very smooth walking gaits even over non-flat surfaces. First, we account for the rail-slider-rocker linkage as a combined system with an articulated body inertia. The rocker's support on the inertial rails means that when linearized around a forward pointing rocker, the system's articulated body inertia has a higher mass in the forward direction than in the vertical direction. Accounting for this difference results in a scaled version of the original inverted pendulum model, where the actual forward acceleration of the center of mass is approximately nine tenths what one would expect given its height and earth's gravity. Additionally, the estimated COM position was adjusted to a body fixed point slightly behind the body fixed COM position used in previous tests.

Third, the controller's response to large impacts necessitates a method to reduce the swing foot landing shock. Although various algorithms have been suggested for this problem, [2] for example, they require accurate models. Instead, we designed a height surface in which the COM height is smoothly reduced at the end of the stepping motion, effectively reducing the impact forces. The ability to change the height surface is one of the key advantages of phase space planning techniques. Finally, the center of mass trajectory is given a speed boost when the foot lifts off the ground. This is an ad-hoc method to regulate the robot speed for smooth walking.

4 Future Goals

Control Framework for High Performance Applications

We are pursuing a cascaded, decentralized control approach, which will allow us to achieve the higher range of impedances necessary to accurately place the swing foot during single support. As a cool application we are pursuing the feat of leaping between a wall and a ladder to achieve parcour-like gaits.

Online System Identification

None of this will be possible without great sensing and an extremely accurate model. We plan to develop an online system identification process and build it into the controller itself so that the robot can improve its dynamic model at runtime. Using an automated differentiation system to calculate the necessary Jacobians, we plan to model the robot as a rigid body system with coulomb friction at the joints.

3D Stabilization

Finally, we will pursue an application of Hume to 3D stepping in various terrains. We will modify our previous 3D phase space planner to generate open loop trajectories and incorporate a suitable sensor based state machine to transition between the phases.

References

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