Continuous-Time Controllers for Robust Stabilization of 3D Bipedal Walking

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***Abstract*—This work presents a systematic approach to design continuous-time feedback laws to robustly and exponentially stabilize periodic orbits for legged robots. A parameterized family of continuous-time feedback laws is considered. By investigating the properties of the Poincaré map, a sensitivity analysis is presented to translate the robust stabilization problem into a set of Bilinear Matrix Inequalities (BMIs). A BMI optimization problem is then setup to tune the parameters of the continuous-time controllers.**

Keywords: Legged locomotion; stability; robust walking; bilinear matrix inequalities.

I. Introduction

We address the problem of designing continuous-time controllers to robustly and exponentially stabilize periodic walking orbits of hybrid models of bipedal robots [1]. Previous work on bipedal walking made use of a multi-level feedback control architecture in which parameters of a continuous-time controller were updated in an event-based manner to achieve stable bipedal walking [2, 3]. One drawback of employing event-based controllers to stabilize orbits is the potentially large delay between the occurrence of a disturbance and the event-based control effort.

II. BMI Optimization for Robust Stability

We present a systematic method based on sensitivity analysis and bilinear matrix inequalities (BMI) to design robust and stabilizing continuous-time controllers that provide exponential stability of orbits without relying on event-based controllers. The method assumes that a parameterized family of continuous-time controllers has been designed so that (1) a periodic orbit is induced, and (2) the orbit is invariant under the choice of parameters. These assumptions are satisfied for several classes of feedback controllers, including LQR with feedforward and certain parametrizations of controllers based on virtual constraints [3]. Through a sensitivity analysis of the Jacobian of the Poincaré return map, we show how to translate the problem of selecting parameters of the continuous-time controller into a BMI optimization problem. Such an optimization problem can be solved easily with available software packages, making this a powerful tool for controller design.

We demonstrate the power of this approach in the design of a robust walking controller for an underactuated 3D bipedal robot with 13 degrees of freedom (see Fig. 1).

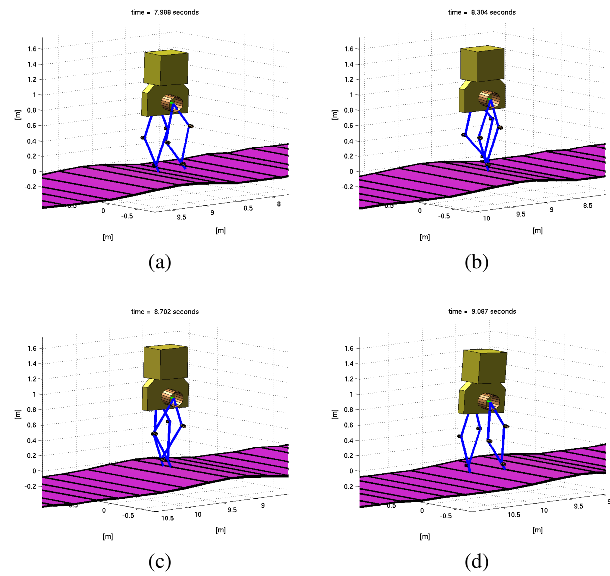

Fig. 1. Simulated 3D walking on uneven ground with point feet.

III. Conclusions

Previous work in the bipedal robot walking literature made use of physical intuition to design virtual constraints [3]. In contrast, the proposed BMI optimization approach provides a *systematic* way to design stabilizing and robust virtual constraints. Furthermore, the method is practical for real legged systems and can be extended to handle additional optimization goals.

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References

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