Control of ATRIAS, an Underactuated Compliant Bipedal Robot, for Walking in 3D

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1 Introduction

ATRIAS (Figure 1) is a human-sized bipedal robot capable of walking and running in 3D, designed and built at the Dynamic Robotics Laboratory of Oregon State University. The leg mechanism of ATRIAS is equipped with passive springs and has been specifically designed to capture the essential characteristics of Spring-Loaded Inverted Pendulum (SLIP) template. Although this special design provides the opportunity of using the insights from the stabilizing controllers of this reduced order model on the robot, the highly underactuated nature of ATRIAS (in single-support it has 12 degrees of freedom and only six actuators) makes the 3D locomotion a totally nontrivial task. In what follows, we briefly discuss our approach and the results obtained so far.

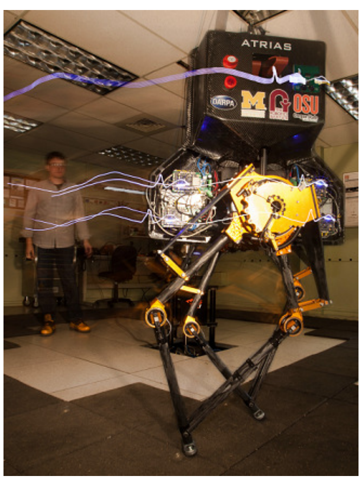

Figure 1. ATRIAS

2 Approach

In our previous work [1], by starting from reduced order models and step-by-step construction towards the full robot, we presented a time-based method for synthesis of stable gaits for 2D walking of ATRIAS. For extension to 3D, we utilize a similar structure with some variations. Motivated by the fact that ATRIAS does not have static equilibrium and needs to constantly switch between the legs to maintain stability, we start by defining a time-based trajectory for a one-dimensional bipedal spring-mass-damper oscillator and showing its global stability (Figure 2. Global stability of the 1D bipedal spring-mass-damper oscillator with a feedforward time-based actuation. Having this globally stable scheme, one can use foot placement and energy regulation as tools for tracking control of the motion of the oscillator in 3D (i.e. forward and lateral degrees of freedom in addition to the vertical one). These tools are accompanied by a method similar to [1] for torso rotational stabilization based on input-output feedback linearization. Furthermore, rather than using high-gain stiff controllers for the motor positions of the compliant degrees of freedom of the robot (as it is essential in Hybrid Zero Dynamics (HZD) [2] and many other trajectory-based control methods), we use low gains, which is equivalent to additional compliance (i.e. impedance control), allowing the robot to stabilize itself in a periodic-orbit dictated by its natural dynamics. Therefore, this approach is fundamentally different from many popular approaches which are based on finding a trajectory and trying to enforce it using high-gain controllers, including HZD and Zero Moment Point (ZMP)-based methods.
In addition to this, for managing unexpected step-downs, an additional module has been added to dissipate the extra energy in such cases and return the robot to its stable walking gait.

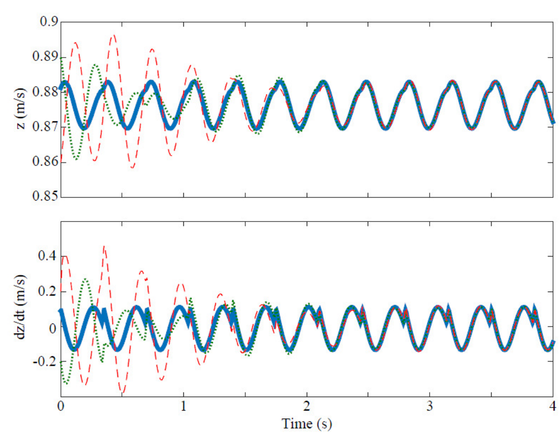

Figure 2. Global stability of the 1D bipedal spring-mass-damper oscillator with a feedforward time-based actuation

3 Current Results

By applying the proposed controller, we conducted experiments on ATRIAS for in-place and forward walking/running, sidestepping, and also managing unexpected step-ups and step-downs as well as soft trains. Both in-place and forward walking experiments have proven the ability of the controller in maintaining the stability and rejecting disturbances such as large pushes and kicks. Figure 3 depicts the velocity tracking of a walking test that eventually becomes running (~7.7 kph). Figure 4 shows the ability of the controller for managing a 15-cm step-down and continuing its normal walking. The most significant limiting factor for achieving higher performance (higher speeds, higher obstacles, etc.) is yaw, as the robot has not been equipped with a yaw actuator, and as the leg force increases, the static friction of the two-point-contact feet is not sufficient to prevent the robot from yawing.

4 Future Works

The proposed controller has shown very encouraging results for stable 3D control of highly underactuated compliant robots such as ATRIAS. As the next step, we intend to change the control scheme in order to decrease yaw oscillations, which in turn will result in achieving more stable walking and running in higher speeds.

5 Acknowledgement

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References

[1] S. Rezazadeh and J. W. Hurst, "Toward Step-by-Step Synthesis of Stable Gaits for Underactuated Compliant Legged Robots," *accepted for 2015 IEEE International Conference on Robotics and Automation (ICRA)*, Seattle, USA, 2015.

[2] J. W. Grizzle, G. Abba, and F. Plestan, "Asymptotically stable walking for biped robots: analysis via systems with impulse effects," *IEEE Trans. Automat. Contr.*, vol. 46, no. 1, pp. 51–64, 2001.

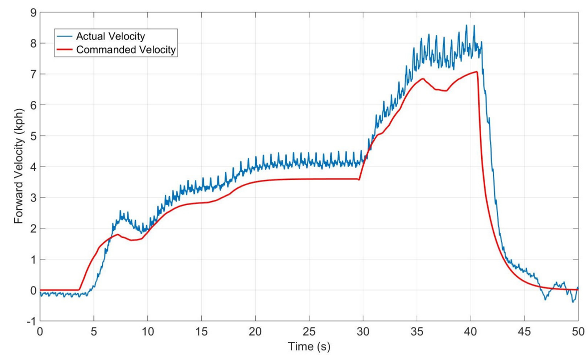

Figure 3. Commanded versus actual (estimated) velocity of a walking/running test of ATRIAS

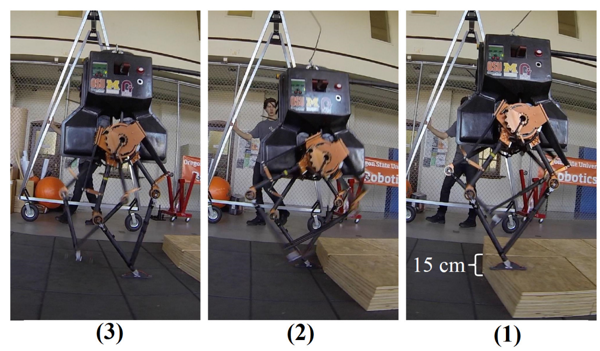

Figure 4. ATRIAS walking over an unexpected 15 cm drop step