Human-Inspired Walking in AMBER 1.0 and AMBER 2.0

Shishir Kolathaya, Ryan Sinnet, Wenlong Ma and Aaron Ames
Texas A&M University
shishirny,rsinnet,wenlongma,aames@tamu.edu

1. Motivation

Human evolution has made the two legs as the only tools for locomotion in humans. In other words, human evolution has made and continuously improved bipedal (two legged) walking to an extent that it can exhibit amazingly robust behaviors over a wide variety of terrains in the environment. This is one of the factors why emulating human walking has been a continued objective for a majority of bipedal walking researchers. Our approach is to carefully understand the dynamics underlying natural human-like walking, apply provable control laws that achieve the desired walking ”pattern” in the robot, and at the same time have human-like nature entwined in these walking controllers.

2. State of the Art

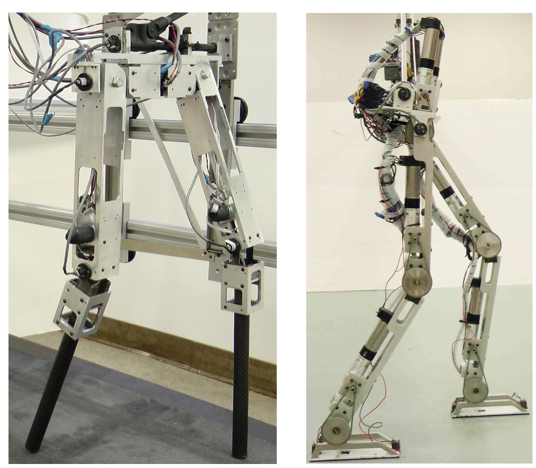
Some of the first fundamental work in the area of legged locomotion was by Marc Raibert, with the idea of achieving locomotion through the use of inverted pendulum models to create single-legged hoppers [10], and Tad Mcgeer who introduced the concept of passive walking [7] (which has also been realized on robots with efficient actuation [4]). Passive walking lead to the notion of controlled symmetries which allows for low energy walking [11], and the Spring Loaded Inverted Pendulum (SLIP) models [6], [9] for running robots. Walking has also been looked as a learning process [8] where the learning algorithm determines an optimal control policy by going through a collection of training sets. In addition to these approaches, several methods have been proposed to directly bridge the gap between biomechanics and control theory by looking at human walking data to build models for bipedal robotic walking (see [5], [12] to name a few).

3. Own Approach

Our approach starts by using outputs and canonical walking functions which intrinsically capture the major characteristics of human walking behavior; this human-inspired control approach thus aims to further bridge the gap between robotics and control by using human walking data to formally design controllers (as first discussed in [3]). Specifically, by considering human walking data obtained through motion capture of subjects walking on flat ground, we find that certain outputs (or virtual constraints) of the human as calculated from this data can be represented by a special class of functions, termed canonical walking functions, characterized as time response of a linear spring-mass-damper system. Thus, humans appear to act like linear spring-mass-damper systems when walking on flat ground. By forming an optimization algorithm, where the cost is the least squares fit of the canonical walking functions to the human walking data, we obtain parameters for a human-inspired controller that provably results in stable under-actuated robotic walking that is as close as possible to human walking. In order to ensure agreement between the simulated behavior of this model and the behavior observed experimentally, this model includes all of the most relevant aspects of the robot including: nonlinear dynamics, models of the motors and boom, and impact dynamics. The end result is a hybrid system model for the bipedal robot, for which the voltage of the motors is the input. Utilizing this model, a nonlinear voltage controller is developed based upon the method of human-inspired control.

4. Current Results

Walking was successfully achieved with both AMBER 1 (Fig. 1a, Fig. 2) and AMBER 2 (Fig. 1b, Fig. 3) by using human-inspired control which is not only stable, but also remarkably robust (see video [1], [2]). In fact, the walking was achieved with minimal computation overhead requiring less than 100 lines of code in LabVIEW. The fact that human walking is an end product of thousands of years



(a) AMBER1. (b) AMBER2.

Fig. 1: The bipedal robot AMBER1 (a) and AMBER2 (b).

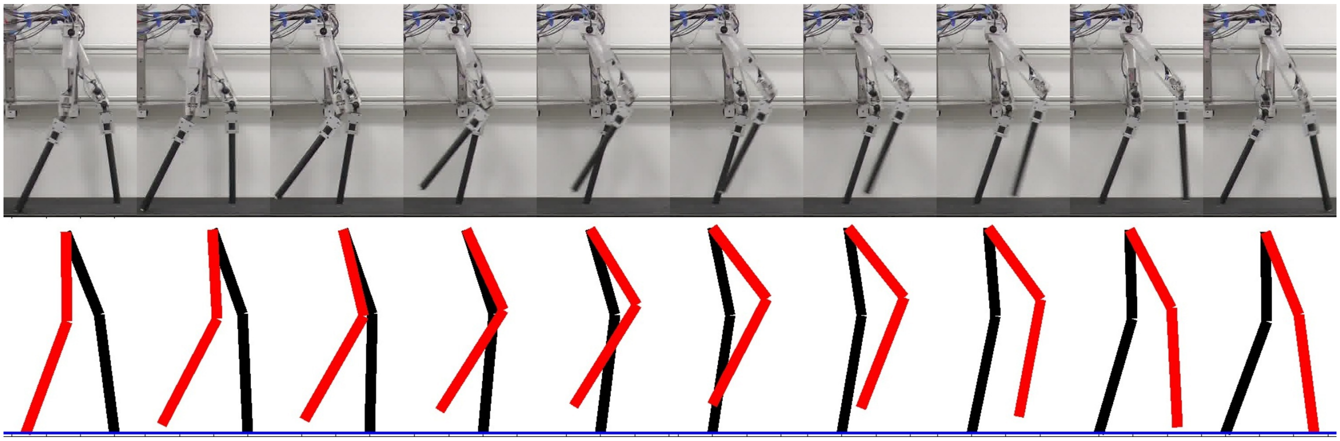


Fig. 2: Experimental (up) and simulated (down) walking tiles for AMBER 1.

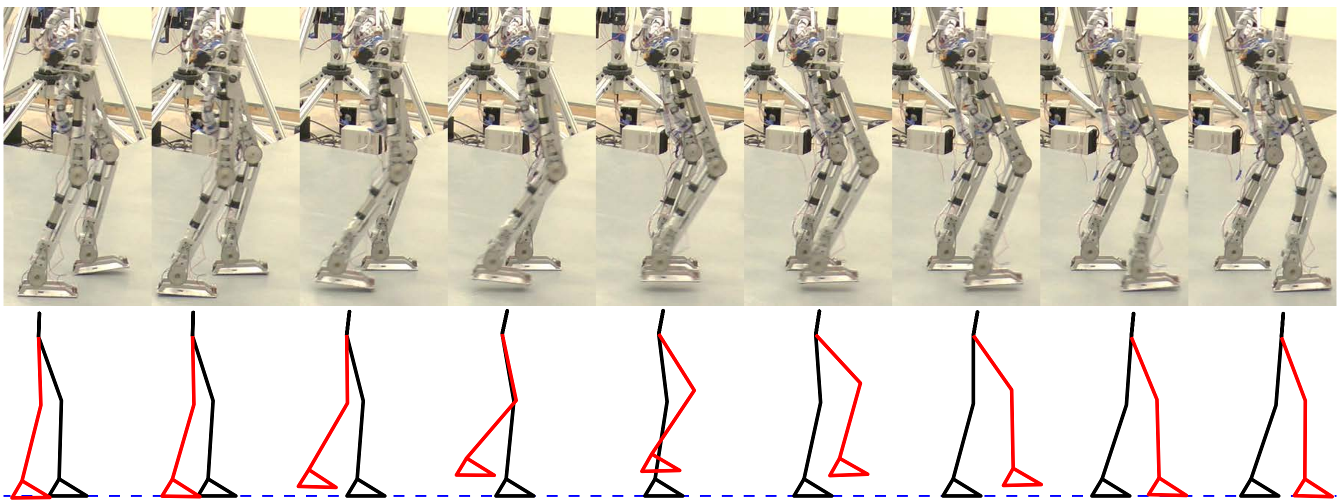


Fig. 3: Experimental (up) and simulated (down) walking tiles for AMBER 2.

of evolution, and that the robustness is inherently built into human walking, shows the extent to which AMBER 1 can be pushed and still walk stablly on the platform.

5. Best Possible Outcome

The robustness shown by the robots can be used as a foundation towards building more robust controllers. The ability to obtain provably stable walking gaits in the simulation and then translate it in the form of a voltage controller in the bipeds establishes a delicate and yet a reliable nexus between theory and experiment, inscribing the formula for success.

References

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