Dynamic Multi-Contact Bipedal Robotic Walking

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***Abstract*—This work presents a formal framework for achieving multi-contact bipedal robotic walking, and realizes this methodology experimentally on two robotic platforms: AMBER2 and ATRIAS. Inspired by the key feature encoded in human walking—multi-contact behavior—this approach begins with the analysis of human locomotion and uses it to motivate the construction of a hybrid system model representing a multi-contact robotic walking gait. Human-inspired outputs are extracted from human locomotion data to characterize the robot model, and then employed to develop the human-inspired control and optimization problem that yields stable multi-domain walking. Through a trajectory reconstruction strategy motivated by the procedure for formally generating robotic walking gaits, the formal result is successfully translated to the two physical robots.**

Key words: Bipedal walking, multi-contact, hybrid zero dynamics

I. Introduction

Human walking exhibits amazingly robustness properties and, therefore, serves as a prime example in the construction of dynamic robot walking gaits. During the course of a step, humans undergo changes in phase, i.e., changes in contact points with the environment, including a heel-lift and a toe strike. This is potentially one of the predominant features of human walking that results in both robustness and efficiency. Achieving human-like bipedal locomotion has been studied from a variety of viewpoints, yet most of which are constrained to point feet walking (hybrid zero dynamics) and flat foot walking (ZMP walking). Noticeably lacking from existing methods is a formal way to generate multi-contact locomotion in a manner that is both formally correct as well as physically realizable.

II. Approach

With the goal of exploring a method to produce multi-contact robotic bipedal locomotion, our approach begins by noting that the multi-contact behavior of human locomotion can be represented as a hybrid system. Therefore, a hybrid system with multiple domains is constructed to describe the multi-contact robotic locomotion in a general form. Further motivated by the human locomotion data, the *extended canonical walking function* (ECWF) is utilized to serve as a low dimensional representation of the human locomotion system. Human-inspired control is utilized to drive outputs of the robot to this representation at an exponential rate. Finally, a novel multi-domain optimization problem is proposed to obtain controller parameters that yield invariant tracking even through impacts. More importantly, this optimization problem is also subject to specific physical constraints, such as torque bounds and scuffing preventions; therefore, the obtained parameters can be implemented on the physical robot directly.

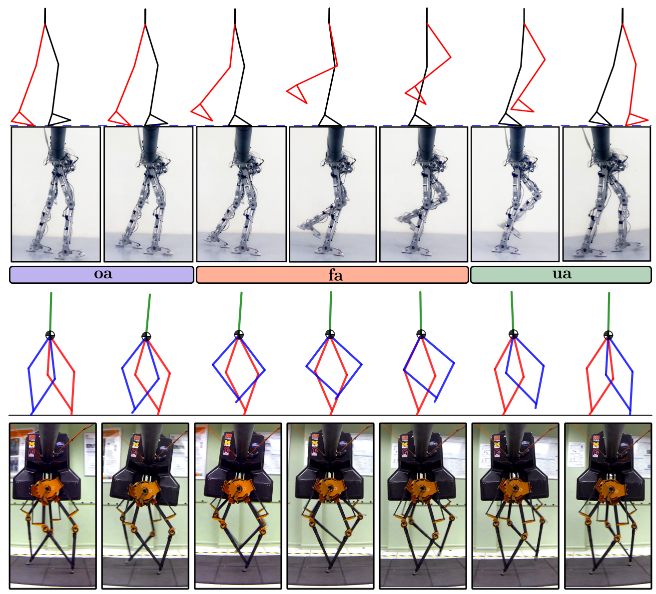

Fig. 1: Comparisons of walking tiles of simulated and experimental walking of AMBER2 (top) and ATRIAS (bottom).

III. Results

The formal results are then implemented on two different robot platforms: AMBER2 (**A**&**M** **B**ipedal **E**xperimental **R**obot 2) with the goal to achieve human-like multi-contact locomotion and ATRIAS (**A**ssume **T**he **R**obot **I**s **A** **S**phere) with the goal of emulating the Spring Loaded Inverted Pendulum (SLIP) multi-contact locomotion. Utilizing a procedure motivated by the formal constructions, we are able to successfully achieve robust human-like multi-contact walking on AMBER2 [1, 2] and SLIP-like multi-contact walking on ATRIAS [3, 4].

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References

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