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Robot Parkour: The Ground Reaction Complex & Dynamic Transitions

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Abstract
Many locomotion tasks on real, complex terrain are poorly modeled as deviations from limit cycles of steady state running. As obstacles become larger and larger relative to leg length, every step is novel and challenging: the leap onto a ledge in Fig. 1 is quite unlike any running step. We seek to organize and systematically reduce this space to a finite set of dynamic transition "words" in order to enable dramatic outdoor transitional behaviors.

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Aaron M. Johnson and D. E. Koditschek

I. Motivation

Many locomotion tasks on real, complex terrain are poorly modeled as deviations from limit cycles of steady state running. As obstacles become larger and larger relative to leg length, every step is novel and challenging: the leap onto a ledge in Fig. 1 is quite unlike any running step. We seek to organize and systematically reduce this space to a finite set of dynamic transition "words" in order to enable dramatic outdoor transitional behaviors.

II. State of the Art

State of the art approaches formulate dynamic transitions as compositions of attractor basins [1, 2]. However even if the environment is exactly and accurately modeled, the full range of possible dynamic transitions will often have a combinatorial character whose representation via a "prepares" graph may not be straightforward and whose direct enumeration might become intractable. Other methods seek to smooth out the discrete nature of hybrid transitions [3], allowing local planning across these boundaries, but without directly exploring the multitude of dynamic interactions that the system affords.

III. Own Approach

Starting in [4], we posited that a better method would be to exploit the intrinsic vocabulary enumerated by the various contact conditions available to a robot whose transitions require that it engage the varied mechanics afforded by its surroundings. Each contact condition defines a hybrid system state with smooth Hamiltonian dynamics, formally generated using self-manipulation [5]. These states fit together as a "ground reaction complex", which for RHex over level ground is a simplicial tetrahedron [4], and whose structure we conjecture may be a bit worse in general but still "regular" enough to codify topologically. This topological structure, together with some properties of the underlying dynamics, indexes the allowable cell transition sequences, or transition "words". In this work, we show a generalization of these ideas to a wider class of robot morphologies, as well as breaking out of the lab and onto more complex terrain.

IV. Current Results

The reward for setting up this cell complex is the generation of an index of all possible dynamic transitions. As first documented in [4], for a simple leaping transition (transitions starting at rest on the ground and ending in the fully aerial cell) each of these words has different properties and may be useful in different situations. Here we present further behavior results derived and informed by this ground reaction complex, now extending to non-flat and outdoor terrain.

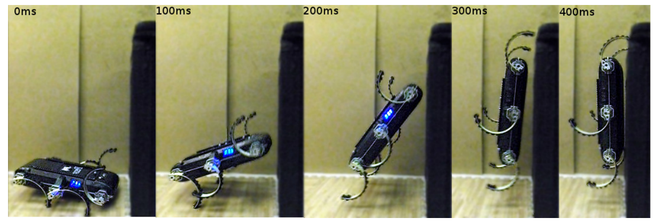

Fig. 1: XRL [6] leaping upward onto a 73cm high table, nearly 1.5 times its bodylength. Frames taken every 100ms from a high speed video.

V. Best Possible Outcome

This work promises to provide an underlying structure for generation and reasoning about dynamic transitions, whether designed by hand or via some automated motion planning algorithm. By indexing systematically all of the hybrid transitions we separate control of the intervening (smooth) Hamiltonian flows from the combinatorics of their succession. For known environments, it should be possible to engage the resulting grammar with appropriate tools allowing a robot to generate these transitions online as it encounters the challenging terrain. We conjecture that even rather different geometries whose surfaces present similar mechanics may give rise to cell complexes whose grammars are also similar enough that a few simple robust "words" might provide an effective basis of transition strategies.

Acknowledgments

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