Dynamic Bipedal Walking on Irregular Terrain: An Online Adaptive Algorithm

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INTRODUCTION

We present a qualitative approach to the dynamical control of bipedal walking that allows us to combine the benefits of passive dynamic walkers with the ability to walk on uneven terrain. We demonstrate an online control strategy, synthesizing a stable walking gait along a sequence of irregularly spaced stepping-stones.

Researchers have recently begun to explore the problem of actuating passive walkers, in order to extend their domain of applicability. In realistic applications, actuation is required for stable walking in level, uphill, or irregular environments, and active planning is essential to allow the robot to react to environmental uncertainty. The algorithmic challenge is to gain the benefits of actuation and active planning without compromising the use of natural dynamics. Our approach to solving this problem uses qualitative descriptions of the dynamics of the system, and a hybrid control framework for composing the walking behavior from simple component behaviors.

METHODS

We consider a slightly modified version of the simple walker models discussed in [1, 2] - we assume that the walker can quickly change the effective length of the swing leg.

Our approach to gait synthesis is based on composing multiple segments of periodic orbits in an online fashion. Instead of constructing a robot to have a single stable periodic gait, we select good orbits from an infinite family of periodic orbits available to our dynamical system and adaptively synthesize a hybrid orbit on each step. This idea is illustrated in the conceptual schematic of figure 1. In this model, the only active control is to apply constant forces for a brief period during the double support phase, to enforce the desirable orbit for the next step. At all other times, the natural nonlinear dynamics are allowed to evolve uncontrolled. Desired orbits are selected by solving an optimization problem that uses a cost based on kinematic specifications (i.e., desirable footholds) and kinetic energy of the stance leg.

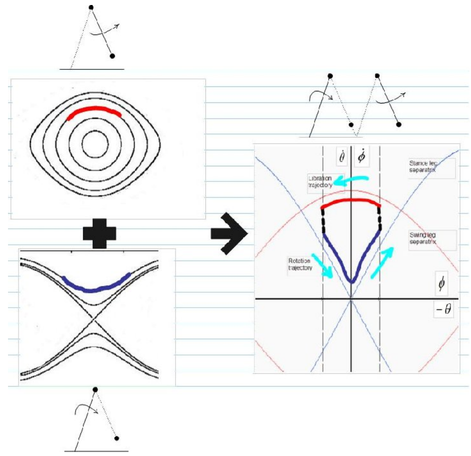

Figure 1. Conceptual schematic of the construction of a hybrid trajectory on each step. The initial conditions of each trajectory are selected by solving an optimization problem, after which the system dynamics evolves uncontrolled.

RESULTS AND DISCUSSION

Figure 2 displays a typical trace of a robot utilizing this algorithm, navigating a flight of stairs. We have obtained similar results for other random terrain situations, e.g., with footholds drawn from a Gaussian distribution in height and forward displacement.

CONCLUSIONS

We address the open problem of actuating passive walkers to navigate uneven terrains and an uncertain environment.

REFERENCES

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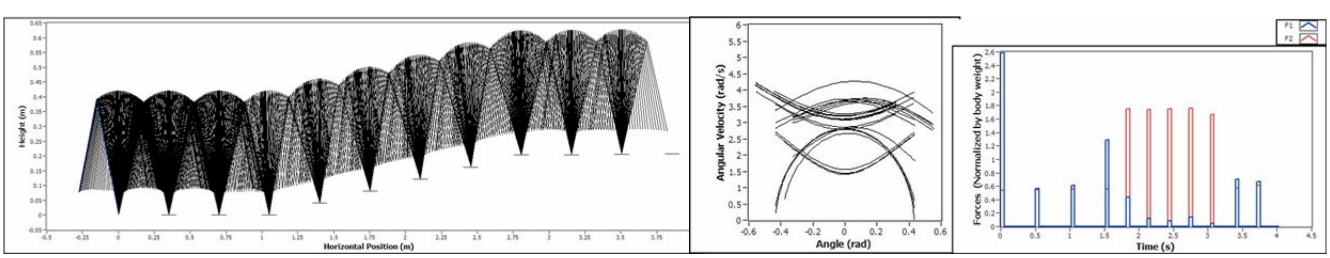

Figure 2. Time capture of robot poses, phase space trajectories and corresponding forces (blue and red correspond to trailing and leading legs respectively) used over time during dynamic walking to climb a flight of stairs.