On the Dynamics of Bounding and Extensions Towards the Half-Bound and the Gallop Gaits

Ioannis Poulakakis, James Andrew Smith and Martin Buehler
poulakas|jasmith|buehler@cim.mcgill.ca

Ambulatory Robotics Laboratory, http://www.mcgill.cim.ca/~arlweb
Centre for Intelligent Machines, McGill University, Montreal, CANADA

1. Introduction

This paper examines how simple control laws stabilize complex running behaviors such as bounding. First, we reveal and discuss the unexpectedly different local and global forward speed versus touchdown angle relationships in the self stabilized SLIP model. Then we show that, even for a much more complex, conservative quadruped model, many cyclic bounding motions exist, which can be locally, open loop stable! These findings might explain the success of simple bounding controllers. This work led to the implementation of the half-bound and rotary gallop asymmetric gaits, on the Scout II quadruped.

2. Self-Stabilization of Bounding

In this paper, the difference between the local and global speed versus touchdown angle relationships in the self stabilized regime of the SLIP model found in [1] was examined. Then the dynamics of the bounding gait is studied. To analyze the properties of the passive dynamics of Scout II in bounding, a return map is derived to study the existence of periodic system motions. Numerical studies of the return map show that passive generation of cyclic motion is possible. Fig. 1 presents a variety of fixed points corresponding to passively generated bounding cycles. Most strikingly, local stability analysis of the return map shows that the dynamics of the open loop passive system alone can confer stability of the motion [2]. Stability improves at higher speeds, a fact which is in agreement with recent results from Biomechanics showing that the dynamics of the body become dominant in determining stability when animals run at high speeds.

3. Introducing Asymmetry: Half-bound and Rotary Gallop

Experimental results using the half-bound and rotary gallop gaits [3] have been performed on Scout II. These gaits, to the authors' knowledge, have never before been performed on a robot. The two controllers are generalizations of the original bounding controller, adding two observable asymmetric states in the front lateral leg pair (legs 1 & 3) and adding control methods for these new states, while maintaining the bound's state machine in the rear legs (legs 2 & 4).

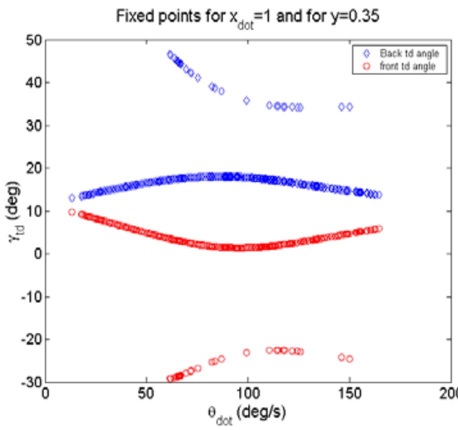

Figure 1. Fixed points at 1m/s and 0.35 m apex height.

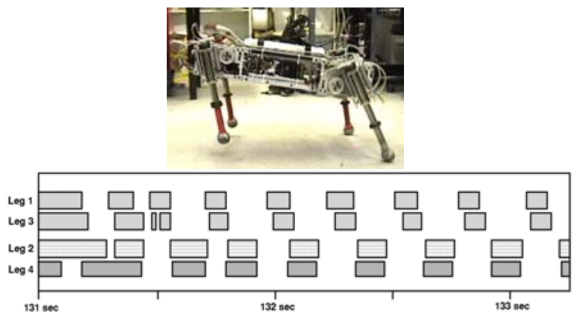

Figure 2. Half-bound stance periods for front and back legs.

4. References

[1] Chigliazza R. M., Altendorfer R., Holmes P. and Koditschek D. E., "Passively Stable Conservative Locomotion", submitted to *SIAM J. of Applied Dynamical Systems*..

[2] Poulakakis I., *On the Passive Dynamics of Quadrupedal Running*, M. Eng. Thesis, McGill University, Montreal, QC, Canada, July 2002.

[3] Hildebrand M., "Analysis of Asymmetrical Gaits" Milton , in *J. of Mammalogy*, Vol. 58, 31, pp. 131-156, 1977.