Open-loop Stability of Time-based vs. Event-based Switching in Locomotion

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1 Motivation and State of the Art

The compass-gait biped and simplest walking model [1,2] have been useful as tools that abstract away the details of a specific walker, allowing the study of properties of the passive nonlinear dynamics. Similarly, the two-link brachiator of Gomes and Ruina [3] has demonstrated that energy-efficient brachiation is possible, i.e., "walking under the surface" (Figure 1). Recently, Rosa et al. [4] introduced the two-link dynamic wall-climbing Gibbot robot that can achieve a "foothold" at any location in the vertical plane, generalizing the compass-gait biped and the two-link brachiator which only have footholds on a line.

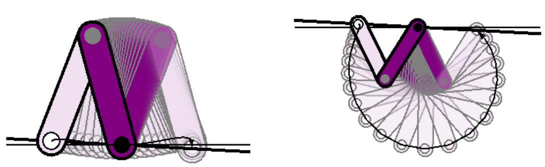

Figure 1: A step by a compass-gait biped (left) and a swing by a two-link brachiator (right) on the same slope. The walker is only stable with event-based switching; the brachiator is stable under both switching strategies.

In this paper, we use this generalized view to show that previously identified compass-gait and brachiation gaits are subsets of a broader set of limit cycles for two-link locomotors. In addition, the generalized framework allows examination of the stability of gaits under event-based switches (e.g., the foot striking the ground) and time-based switches (e.g., an electromagnet of the Gibbot clamping onto the wall at a given time). While all event-based gaits are also time-based gaits, the switching strategy has a profound effect on the stability of open-loop gaits. The environmental feedback provided by a fixed slope "floor" or "ceiling" constraint can have a significant stabilizing effect not present in a time-based switching strategy.

2 Approach

In our framework, we define a gait as a fixed point of a two-link robot's hybrid dynamics. A fixed point is stable if the absolute value of the maximum eigenvalue of the dynamics's Jacobian evaluated at the fixed point is less than one. To allow for uphill gaits, we provide an actuator at the middle joint, which makes powered stable open-loop uphill gaits possible. In this paper, we restrict ourselves to passive gaits focusing on the impact strategies. An event-based impact occurs when the robot's swing leg reaches a fixed slope, while time-based impacts occur after an elapsed period of time. We use numerical continuation methods [5] to trace solution families using each switching strategy. The number of free variables and constraints are slightly different for each impact type, but both systems yield the same disconnected 1-D solution families of fixed points.

3 Current Results

We have found that event-based impacts are more stable. In particular, a stable time-based gait is also a stable event-based gait, but not vice-versa. The most striking example occurs with walking gaits, which cannot be made stable under time-based impacts. Furthermore, for the same solution family, event-based impacts undergo period-doubling bifurcations while time-based impacts undergo Neimark-Sacker bifurcations (stable period-1 fixed points become stable period-n periodic or quasi-periodic limit sets, $n > 1$) taking a Ruelle-Takens-Newhouse route into chaos.

4 Best Possible Outcome

While we have shown the stabilizing effects of impacting on a fixed slope versus fixed time for both gaits, walking and brachiating are rarely treated together. Since they share similar dynamics, a well-designed walking robot might also be made to brachiate. This work is a step toward understanding the multi-locomotion capabilities and open- and closed-loop stable gaits of an articulated robot as a function of the switching strategy and the "footholds" provided by the environment: a floor for walking, a "ceiling" for brachiating, a continuous wall for the Gibbot, and, in future, regular or irregular discrete footholds.

Acknowledgment

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References

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