Quantifying the Robustness of Natural Dynamics: a Viability Approach

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I. Summary

Stable running can be achieved both through active control as well as a purely passive mechanical design [1]. As a rule of thumb, purely passive systems have very small basins of attraction [2], and feedback control is essential for robust, versatile motion. Nonetheless, well-designed systems exhibiting favorable natural dynamics can greatly simplify the controller design and greatly aid robustness [3], [4], also in animals [5]. It is, however, difficult to quantify the contribution towards robustness of the mechanical design, compared to the low-level controller implementation, or the overall high-level planner. We present a viability-based approach to rigorously quantify the inherent robustness of a system, valid for the family of all robust control policies [6]. This allows us to quantify the robustness inherent to the natural dynamics (i.e., the mechanical design), before specifying the actual control policy, policy parameterization or even control objective.

II. Presentation

We will present an illustrative example using spring-loaded inverted pendulum (SLIP) example. The main challenge to our approach is the curse of dimensionality. We would like to discuss our ongoing work on scaling up our approach, which we expect to be able to scale to 6-10 dimensions. Our current focus is on using simulations of the SLIP model as a prior for Gaussian mixture models, and then refining this online from data collected on the actual robot. We are also looking for questions which can benefit from our quantification, and can be answered with systems well-represented by simple models, where we can directly apply our quantification via brute-force.

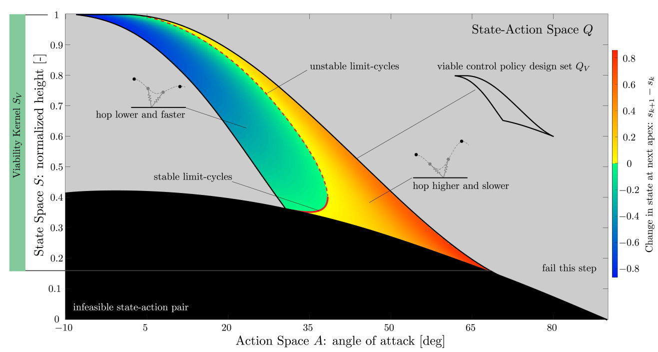

Fig. 1. reproduced from [6]. The figure shows the viable (non-failing) set in state-action space for the energy-conservative SLIP model, evaluated on a Poincaré at flight apex. The vertical axis shows the state defined as potential over total energy. At flight apex, the height contains all potential energy, and the forward velocity contains all kinetic energy. The state is thus a normalized height. The horizontal axis shows the available control action: the landing angle of attack. State-action pairs in the gray region fail one step. State-actions in the warm and cool colored regions result in hopping higher and lower respectively, with the color indicating the change in state (vertical axis) at the next apex. Also marked are passively stable (solid red) and unstable (dashed red) limit-cycles, where the state does not change.

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