

The Positive Side of Damping

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The intrinsic compliant properties of muscles are essential for adaptive locomotion in animals. The importance of spring-like behavior in stabilizing unexpected perturbations has been shown by Daley and Biewener [1], who compared simulations of the spring-loaded inverted pendulum (SLIP) model of running with experimental data of running birds. This spring-like behavior is often reproduced in legged robots, for example through impedance control [2] or virtual model control [3], [4].

Damping also plays a role in stability. For example, Haeufle et al. have shown that both active and passive damping properties in muscles contribute to stability in a simple hopping model [5]. Birn-Jeffery et al. also show that including damping in a modified version of the SLIP model results in ground-reaction force profiles which more closely match experimental data [6]. In machines, however, engineers generally put considerable effort into minimizing passive damping, since it leads to loss in energetic efficiency.

These studies have focused on stability in the classical sense: convergence to an equilibrium point or limit-cycle. However, Birn-Jeffery et al. have shown that convergence to limit-cycle motion is not a control priority for running birds [6], and suggest that a more general task-level definition of stability, such as "don't fall", would be more appropriate.

Heim and Spröwitz have recently developed a quantification of robustness based on viable sets in state-action space [7]. This approach begins with a generic definition of failures and provides a quantification of robustness which includes all non-failing actions. In other words, instead of evaluating stability in the classical sense, a system maintains viability as long as it can continue to avoid failure. A system is robust if it can remain viable despite uncertainties such as noise or perturbations. In this sense, an action which diverges from a limit-cycle may still be viable, as long as it does not lead to unavoidable failure. The novelty of this formulation is that robustness due to intrinsic properties can be quantified without making assumptions on the control policy.

We propose a systematic study of the effect of intrinsic damping on robustness, using a modified version of the SLIP model, similar to [6], but in the context of unexpected ground-level perturbations [1]. From Daley et al.'s studies, active control does not play a significant role in the first step when birds deal with unexpected perturbations [8], and only intrinsic properties come into play. A viability-based evaluation

is thus particularly well suited to this type of perturbation in running.

We expect our results to provide a quantitative measure of the effect of damping on the stability at task-level abstraction. In addition to shedding new light on how animals manage to cope with robustness requirements, a quantification would allow engineers to purposefully add physical damping to robot designs, with a known trade-off between robustness and energetic efficiency.

References

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