Fall avoidance via hierarchical task-switching control of the simplest dynamic walker

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***Abstract*—Do humans resolve task-level redundancies during walking partly by choosing regulation strategies from the perspective of fall avoidance? Recently, we found that experimentally informed task-level regulation, despite not being designed to do so, makes treadmill walking more robust to large external disturbances. These simulation results demonstrate a functional connection between task-level motor regulation and global stability. Here, we posit a hierarchical control that, in principle, allows switching between different task-level regulators to avoid falls in the simplest dynamic walker. We identify the walker's viability kernel—a region in its state space in which it can step indefinitely by push-off control. We find that only a few of the task-regulated walker's basins of attraction of its period-1 gaits can fully cover the viability kernel. Therefore, this suggests a hierarchical parametric task-switching control scheme for the walker to remain viable (i.e., avoid falls) forever.**

***Index Terms*—fall avoidance, viability, motor control, task-level regulation, basin of attraction, bipedal walking**

I. Introduction and Methods

While walking humans remain upright via active neuromotor control, they also need to choose from multiple regulation strategies to achieve one or more task goals, such as maintaining a desired speed or direction. Our recent work [1] suggests that humans might select step-to-step task-level regulation strategies that most enhance motor robustness or, perhaps, decrease their fall risk. Building on this prior work, here we posit a hierarchical control of the simplest dynamic walker by switching between different task-level regulators such that the walker can, in principle, avoid falls forever.

We used a 2D compass walker [2] on a treadmill with push-off P applied just before heel strike. We imposed different experimentally informed task-level regulation strategies, including step-to-step speed regulation, on the walker and compared its ability to reject large state disturbances via basins of attraction of its period-1 gaits in the state space [1]. We also estimated the walker's viability kernel $\mathcal{V}$ [3] i.e. the set of states beginning in which the walker can step forever by actively modulating P.

II. Results and Discussion

The open-loop basins are quite thin with many disjoint boundaries: Collectively, these basins occupy no more than 40% of the area of $\mathcal{V}$, irrespective of how many of them are chosen. On the contrary, the speed-regulated basins are geometrically simple and occupy large areas within $\mathcal{V}$ (Fig. 1): only five such basins almost fully cover $\mathcal{V}$. This suggests a hierarchical control strategy to achieve viable walking: The walker's state is moved from one speed-regulated basin to another by simply switching between a few target step speeds V_i^*. Once the walker's state reaches the required basin, switching stops. We also found that the treadmill walker could recover faster from external disturbances by switching between a few different types of regulators, such as the step length, step time, and absolute position regulators.

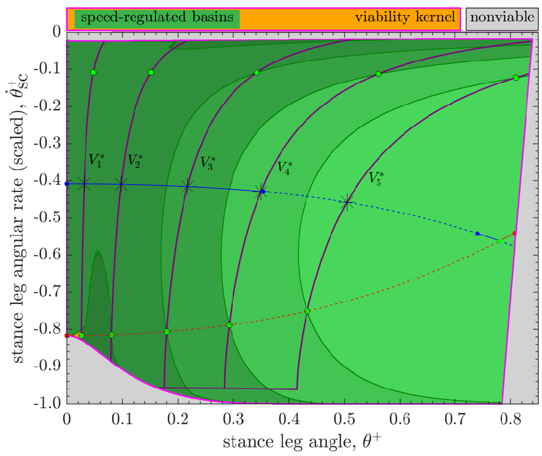

Fig. 1. Together, the speed-regulated walker's basins of its period-1 steady-state gait (⊛) at five different target step speeds, $V_i^* \in \{0.016, 0.051, 0.113, 0.178, 0.251\}$, cover $> 99.99\%$ of the area of the viability kernel. Each *purple* curve is a target-speed manifold at V_i^*.

Our results show that the task-level regulators are particularly suitable for achieving viable walking via a high-level task-switching controller. Furthermore, the "information cost" of implementing such hierarchical control could be relatively low for the nervous system, as it requires specification of a single switching parameter at each walking step.

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References

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