An energy landscape approach to legged locomotion through large obstacles

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I. INTRODUCTION

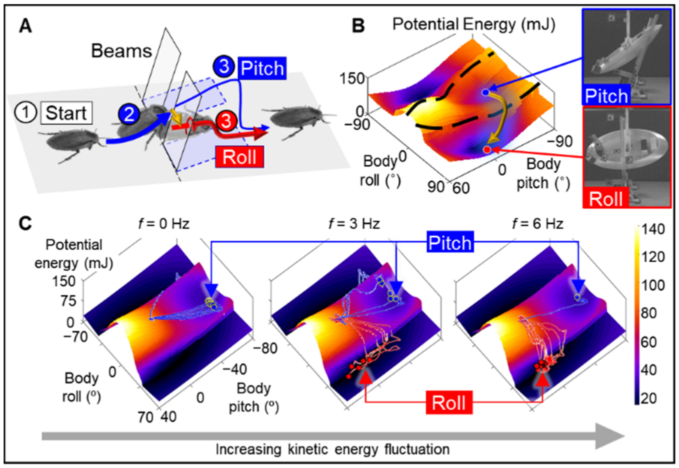
Critical applications like search and rescue require robots to traverse complex terrain like earthquake rubble with many large obstacles. Yet robots still struggle to do so [1] because the traditional approaches of path planning are often based on geometric information of the environment alone and only allow obstacle avoidance, but not robust traversal. By contrast, animals are exceptionally good at traversing complex terrain with large obstacles. They often do so by transitioning across different forms of movement, using effective physical interaction. However, the physical principles of how locomotor transitions emerge from physical interaction with large obstacles are not well understood.

Recent studies revealed that locomotor transitions during legged traversal of complex terrain occur via multiple pathways [2]. To traverse cluttered grass-like beams, insects can climb over, push across, reorient body to maneuver through beams gaps or even transition among these modes. Inspired by free energy landscape that enabled understanding and prediction of multi-pathway protein folding [3], we contend that an energy landscape approach helps understand locomotor transitions in complex terrain. Specifically, we hypothesized that: (1) locomotor transitions emerge as the system crosses barriers on a potential energy landscape to hop from one local minimum basin to another; (2) kinetic energy fluctuation from oscillatory leg propulsion helps the system overcome barriers to make transitions; and (3) the system tends to escape more towards directions with lower barriers.

II. METHODS & RESULTS

We test our hypotheses in a model system—traversal of grass-like beam obstacles—focusing on the transition between two representative modes: (1) Pitch. During traversal the animal first approaches the beams and pushes against them, and beam elastic restoring forces cause its body to pitch up (Fig. 1A, blue). As the animal continues to push across the beams to traverse, it maintains a slightly pitched up body posture. (2) Roll. Instead of pushing across, the animal can transition to rolling its body into the gap between the beams and maneuver through to traverse (Fig. 1A, red).

Besides animal experiments, we developed a simplistic robot (Fig. 1B, inset) and used it as a physical model to enable systematic variation of kinetic energy fluctuation. We challenged both the animal and robot to traverse beam obstacles, measured 3-D motion of both the body and beams, and reconstructed the system's potential energy landscape and how system state trajectory behaved on it. We also compared the measured kinetic energy fluctuation with the measured potential energy barrier.



For both the animal and robot, we discovered that its state was strongly attracted to a "pitch" local minimum basin when it pushed across the beams, but it escaped from it to find a "roll" basin when it transitioned to the roll mode (Fig. 1B). In addition, as kinetic energy fluctuation increased, the robot was more likely to escape from the pitch basin and transition to the roll basin (Fig. 1C). Further, the robot escaped more frequently towards the saddle between the pitch and roll basins, which had the lowest barrier. These results supported our hypotheses.

III. DISCUSSION

We envision an energy landscape approach as the beginning of a statistical physics framework to understand and predict how locomotor transitions emerge from physical interaction with complex 3-D terrain. This will complement geometry-based obstacle avoidance approaches to enable robots to make robust locomotor transitions to traverse the real world.

REFERENCES

[1] E. Guizzo and E. Ackerman, "The hard lessons of DARPA's robotics challenge," *IEEE Spectr.*, vol. 52, no. 8, pp. 11–13, 2015.

[2] C. Li, A. O. Pullin, D. W. Haldane, H. K. Lam, R. S. Fearing, and R. J. Full, "Terradynamically streamlined shapes in animals and robots enhance traversability through densely cluttered terrain," *Bioinspiration and Biomimetics*, vol. 10, no. 4, p. 46003, 2015.

[3] J. N. Onuchic, Z. Luthey-Schulten, and P. G. Wolynes, "Theory of protein folding: the energy landscape perspective.," *Annu. Rev. Phys. Chem.*, vol. 48, no. 1, pp. 545–600, Jan. 1997.

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