Active tail helps legged robots dynamically traverse large gap and bump obstacles

Sean W. Gart, Changxin Yan, Ratan Othayoth, Zhiyi Ren, and Chen Li (chen.li@jhu.edu, https://li.me.jhu.edu)
Department of Mechanical Engineering, Johns Hopkins University

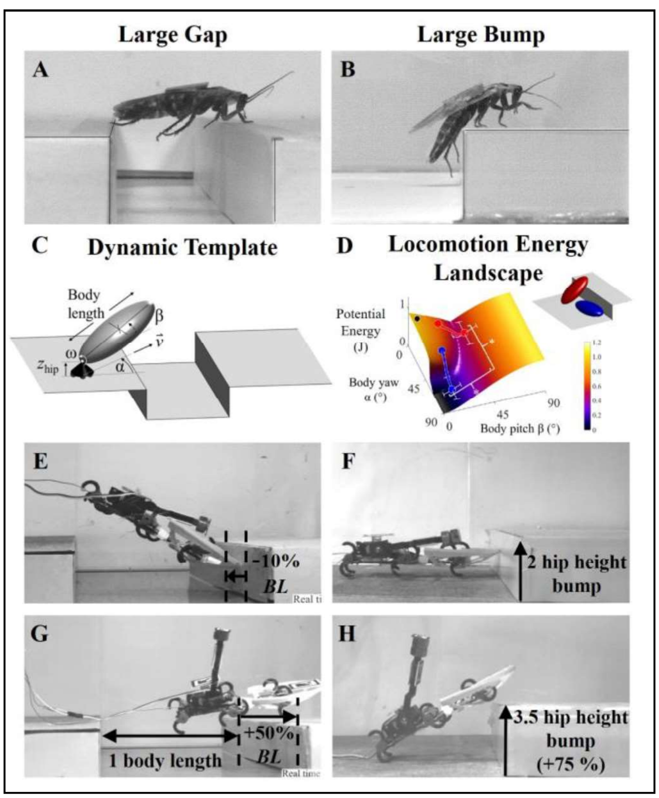
I. Introduction

Small search-and-rescue and environment-monitoring robots must rapidly traverse cluttered 3-D terrain such as earthquake rubble and underground tunnels filled with large obstacles comparable to themselves. In this case, the classical approach of obstacle avoidance using a geometric representation of the environment becomes insufficient. Small animals like insects and reptiles can traverse a variety of cluttered 3-D terrain such as forests and mountains. Understanding the physics principles of how animals take advantage of effective physical interaction with the terrain during dynamic locomotion can help us improve robot performance and enable them to traverse a wider range of complex 3-D terrain.

II. Methods & Results

Here, we studied dynamic locomotion of insects and legged robots over a large gap [1] and a large bump [2] to begin to understand dynamic traversal of large 3-D obstacles. To discover general principles, we varied the gap width (relative to body length) and bump height (relative to the hip height) and challenged the insects and robots to rapidly traverse them.

Remarkably, both the animal (Fig 1A-1B) and the robot (Fig 1E-1F) were able to dynamically traverse a large gap of up to 80% its body length and a large bump of up to 2 times its hip height at speeds comparable to that during running. In addition, we discovered that probability of gap traversal decreased as gap width increased and traversal was well predicted by whether the head bridged across the gap. Bump traversal was more likely with a higher initial body pitch and less likely for larger bumps.



Based on these observations, we developed a simple, reduced-order, dynamic template [3] for gap traversal (Fig. 1C) and a locomotion energy landscape model [4] for bump traversal (Fig. 1D). Both models explained the dependence of traversal performance on locomotor and terrain parameters as observed in the experiments. In addition, the models predicted that a more pitched up body posture while approaching the gap or bump increases the chances of traversal and will enable the robot to traverse larger gaps and taller bumps.

To test this prediction, we added an active tail [5], [6] to the legged robot to increase its body pitch as it approached the gap (Fig 1G) or bump (Fig 1H). As our models predicted, by pitching the body up, the active tail increased the probability of the robot traversing any gap or bump obstacle of a given size. Remarkably, this increased the robot's maximal traversable gap length from 1 to 1.5 times its body length, a 50% improvement, and increased the robot's maximal traversable bump height from 2 to 3.5 times its hip height, a 75% improvement.

III. Conclusions

By integrating biological and robotic experiments and physics modeling, we discovered the principles of dynamic traversal of a large gap and a large bump obstacles. We also developed the first dynamic template for locomotion in a 3-D terrain (a large gap) and expanded the locomotion energy landscape framework [2] to model a new 3-D terrain (a large bump). Our study is a major step in establishing the emerging field of terradynamics [1], [4] of locomotion in complex 3-D terrain.

References

[1] S. W. Gart C. Yan, R. Othayoth, Z. Ren, and C. Li, "Dynamic traversal of large gaps by insects and legged robots reveals a template," *Bioinspir. Biomim*, 2017.
[2] S. W. Gart and C. Li, "Body-terrain interaction affects large bump traversal of insects and legged robots," *Bioinspir. Biomim*, 2017.
[3] D. E. Koditschek and R. J. Full, "Templates and anchors: neuromechanical hypotheses of legged locomotion on land," *J. Exp. Biol.*, vol. 2, no. 12, pp. 3–125, 1999.
[4] 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.," *Bioinspir. Biomim.*, vol. 10, no. 4, p. 046003, 2015.
[5] A. Johnson, T. Libby, E. Chang-Siu, M. Tomizuka, R. Full, and D. Koditschek, "Tail assisted dynamic self righting," *Proc. Fifteenth Int. Conf. Climbing Walk. Robot. Support Technol. Mob. Mach. Balt. MD, USA, 23 - 26 July 2012*, vol. 1, no. July, pp. 612–620, 2012.
[6] E. Chang-Siu, T. Libby, M. Brown, R. J. Full, and M. Tomizuka, "A nonlinear feedback controller for aerial self-righting by a tailed robot," *Proc. - IEEE Int. Conf. Robot. Autom.*, pp. 32–39, 2013.

This work is supported by an ARO YIP (grant # W911NF-17-1-0346), a BWF CASI, and JHU WSE startup funds to C.L.