Locomotion energy landscape guides the design of legged robot gait for traversing large obstacles

Yuanfeng Han, Yulong Wang, and Chen Li (chen.li@jhu.edu, https://li.me.jhu.edu)
Department of Mechanical Engineering, Johns Hopkins University

I. Introduction

Traditional path planning algorithms [1] help mobile robots avoid sparse obstacles using a geometric model of the environment. However, many important applications require robots to move through cluttered environments, where they inevitably interact physically with multiple 3-D obstacles (e.g., traversing earthquake rubble for search and rescue). These applications still challenge even the best terrestrial robots, because we understand little about the physics of locomotor-terrain interaction in such terrain [2]. By contrast, many small animals agilely traverse complex terrain using effective physical interaction. Analogous to aerodynamics that helped us control airplanes to fly in complex fluid flow, understanding the physics of locomotor-terrain interaction can help us design new gaits for legged robots to traverse complex 3-D terrain using effective physical interaction.

II. Locomotion Experiments

To gain insight into how legged animals actively adjust its body and leg motion to traverse cluttered obstacles in complex 3-D terrain, we compared the locomotion of the discoid cockroach and a sensor-less, RHex-class, legged robot physically negotiating a vertical pillar obstacle. With a cuboidal body shape, both the animal and the robot were always attracted towards the obstacle and pitched up. The robot never escaped the obstacle attraction and always ended up flipping-over (100% probability); by contrast, the animal never flipped over (0% probability) and frequently adjusted its legs to turn its body to the side to escape the attraction from the obstacle (63 ± 5%). We noticed that the animal's turning escape often occurred after its body pitched up substantially.

III. Physics Modeling

To gain insight into the physics of locomotor-terrain interaction and provide a tool for designing new gaits for legged robots to traverse the obstacle, we developed a locomotion energy landscape model (Fig. 1). Our model well explained why the forward-moving locomotor with a cuboidal shape was attracted to the obstacle (Fig. 1A). In addition, the model predicted that the attractive torque (potential energy gradient along the heading direction) towards the obstacle decreased as body pitch increased (Fig. 1B). This meant that, if the robot pitches up more, it needs less torque from leg adjustment to turn its body to escape the obstacle.

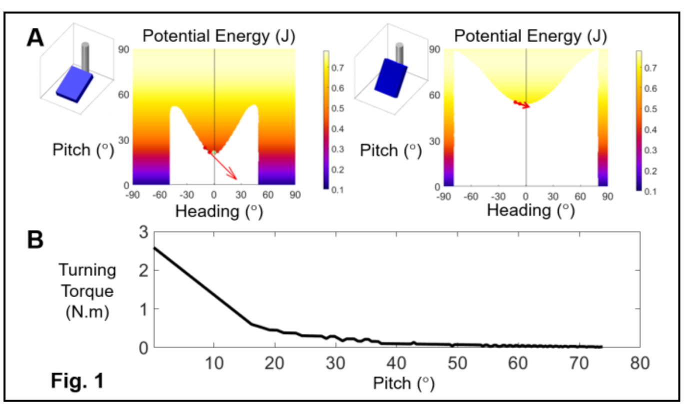

Fig. 1

IV. New Gait For Traversal

Guided by these biological observations and physics insight, we designed a novel gait for the legged robot to escape attraction by the obstacle (Fig. 2). The robot first passively negotiated the obstacle using a feedforward alternating tripod gait and was attracted towards the obstacle (Fig. 2A, B). As the robot body pitched up (Fig. 2B, C), the two rear legs were adjusted to rotate in opposite directions to generate a torque to turn the body (Fig. 2C, D), and the robot managed to escape the obstacle (Fig. 2D, E).

Using a force/torque sensor embedded in the robot body, we found that body pitching up reduced the torque required to overcome obstacle attraction, consistent with our model prediction. Unless the robot pitched to higher than a critical angle of 40°, the turning torque generated by the legs pushing against the ground was not sufficient to overcome the turning torque from the obstacle. This suggested that the model can also guide the planning of when the robot should adjust its gait to traverse obstacles. We are currently working on integrating onboard IMU and force/torque sensors to measure body pitch and attractive torque and adding sensory feedback control to initiate the gait change at the right time to traverse the obstacle.

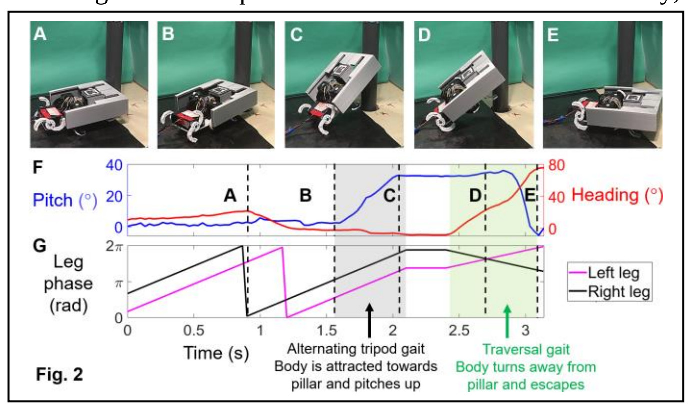

Fig. 2

We envision that such a novel physics-based control and planning approach will enable legged robot to traverse a diversity of complex 3-D terrain.

References

[1] H. Choset, S. Hutchinson, K. Lynch, and G. Kantor, *Principles of robot motion: theory, algorithms, and implementation*. 2005.

[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.