Body shape modulates obstacle attraction and repulsion during dynamic legged locomotion

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I. INTRODUCTION

Complex terrain such as earthquake rubble, forest floor, and cluttered buildings have large 3-D obstacles which challenge even the best terrestrial robots. This is largely because the traditional path-planning approaches based on geometric maps mostly avoid obstacles (rather than traversing them). There is a relative lack of understanding of the physics of locomotor-terrain interaction and how to design and control robots to physically interact with obstacles to traverse them.

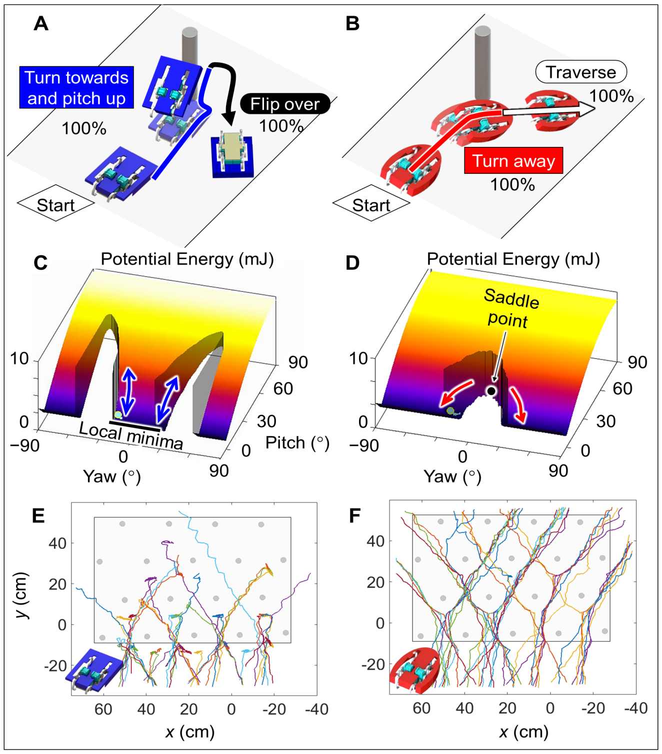
Many small terrestrial animals move well through cluttered terrain, where their body and appendages constantly interact physically with the environment. Analogous to aerial and aquatic animals and vehicles with aerodynamic and hydrodynamic body shapes that facilitate locomotion in water and air, there may exist "terradynamic" shapes [1], [2] whose physical interaction with the terrain during locomotion can help animals and robots better traverse cluttered terrain.

II. METHODS & RESULTS

Here, to begin to understand obstacle interaction during dynamic locomotion, we studied how two different body shapes interacted with the obstacles during dynamic locomotion by attaching cuboidal (Fig. 1A) and elliptical (Fig. 1B) outer shells to animals and robots. We discovered that the cuboidal body shape almost always attracted the animal (88 ± 5% probability) and the robot (100 ± 0% probability) towards the obstacle (Fig. 1A). Continued pushing against the obstacle resulted in the robot body pitching up and eventually flipping over (Fig. 1A). By contrast, for both animals and robots, the elliptical body shape almost always repelled the animal (95 ± 2% probability) and the robot (100 ± 0% probability) away from the obstacle, facilitating traversal (Fig. 1B). In addition, these interactions were insensitive to the shape and orientation of the obstacle.

To explain how attraction/repulsion emerges from body-obstacle interaction, we developed a potential energy landscape model, whose distinct topology revealed that cuboidal and elliptical shapes resulted in attractive and repulsive interactions, respectively. A cuboidal shape resulted in body being stuck in a narrow local minimum basin with infinite barriers on either side (Fig. 1C). Leg propulsion induced the system to move, but high barriers precluded yawing and caused the body to pitch up and be attracted towards the obstacle. By contrast, an elliptical shape resulted in a repulsive potential energy landscape, inducing the body to yaw and be repelled away from the obstacle (Fig. 1D).

Understanding shape-modulated obstacle interaction could guide task-dependent robot design (for e.g., a cuboidal body for scaling pillars, an elliptical body for fast traversal). To demonstrate the use of shape-modulated obstacle repulsion and attraction, we challenged a feedforward robot to traverse a cluttered obstacle field. The cuboidal robot was attracted to obstacles and remained stuck (Fig. 1E), compared to an elliptical robot which always traversed further and cleared the obstacle field (Fig. 1F). In addition, we showed that a drone can use a cuboidal body shape to be passively attracted to an obstacle to perch, using the same principle. Finally, our model suggested that during self-propelled, dynamic locomotion, obstacle attraction and repulsion is only dependent on locomotor body shape but is insensitive to obstacle shape.



III. BROADER IMPLICATIONS

More broadly, understanding how body shape variation alters the topology of potential energy landscape to result in attractive basins and repulsive peaks in the parameter space can inform how to design shapes and shape-morphing strategies to elicit desired locomotor transitions.

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