Sensing physical interaction to better traverse cluttered obstacles

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I. Introduction

When vehicles and robots encounter obstacles, their primary way of "traversal" is to track a planned trajectory that safely avoids all obstacles using a geometric map of the environment. Instead of avoiding obstacles, animals usually move through complex terrain using physical interaction with obstacles. Previous studies showed that a cockroach could traverse cluttered, grass-like beams successfully [1] and chose different strategies when encountering beams with different stiffness [2]. When the beams were flimsy, the cockroach simply pushed down the beams to traverse. When the beams were stiff, the cockroach rolled its body to traverse the gap. However, the cockroach could not differentiate stiff and flimsy beams from the geometric information alone. Thus, it is likely that they used physical interaction to sense how stiff the obstacles were, and chose their strategy to traverse. Here, we built a bio-inspired, beam traversal model to demonstrate how to obtain the stiffness and the bending positions of beams using force sensing during physical interaction and use this information to plan and control the system to traverse beams.

II. Model Design

The cockroach was approximated as an ellipsoidal rigid body driven forward by a propulsive force F (Fig. 1B, the thick, black arrow). Each beam was approximated as two massless, rigid segments with a torsion spring as a connection (Fig. 1C). The bottom segment was upright, and the height of the spring from the ground was Δh (the bending position of the beam). As a first step, we assumed that all cockroach-beam contacts were quasi-static and frictionless, and contact forces were normal to the ellipsoidal body (Fig. 1B).

III. Sensing, Motion planning, and control

The ellipsoidal body did not know the stiffness k and Δh of the beam until they were solved from force sensing data $\vec{F}_{sensing}$. $\vec{F}_{sensing}$ were sampled during interaction with obstacles. By comparing $\vec{F}_{sensing}$ with the force $\vec{F}_{total}(k, \Delta h)$ from modelling (Fig. 1B), we used least squares regression to solve the unknown variables.

Knowing the stiffness and bending position of beams helps in motion planning and control through a potential energy landscape approach. A potential energy landscape of a similar beam traversal model was introduced in a previous work [2], which combined the geometric map and the stiffness of the beams. We created a dual-direction network based on the potential energy landscape and searched for the planned trajectory with minimum cost using Dijkstra's algorithm. Based on motion planning, we used the feedback linearization control to track the planned trajectory (Fig. 1D).

The motion planning results showed that when encountering the flimsy/stiff beams, the body chose the same pushing/rolling strategy as cockroaches, respectively. In the case of encountering stiff beams, the simulation results showed that in the case of without control, the body traversed the beams by pushing down beams with higher energy cost compared to the case with control.

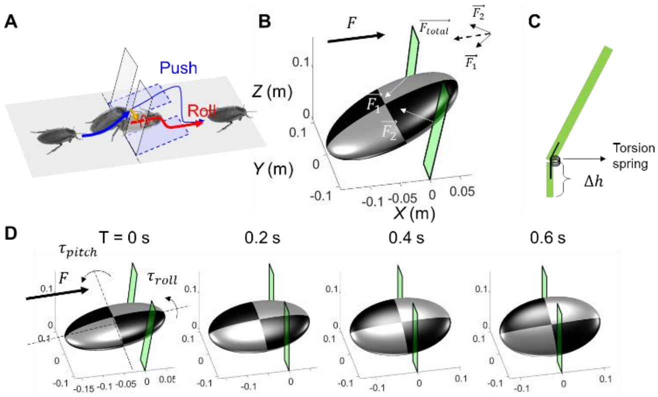

Figure 1: Cockroach beam traversal model design. (A) Two main strategies for a cockroach to traverse the beams. (B) Cockroach is modeled as an ellipsoidal rigid body. (C) Beam model. (D) Snapshots of traversal under control.

IV. Future work

We only considered the change of potential energy in current motion planning. Our next step is to consider kinetic energy and dynamics in motion planning and further improve the traversal performance. We are also developing a robotic physical model with force sensors to validate our model and systematically study the principles of force sensing feedback over the system's state space [3].

References

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