The importance of appendage coordination during leg-assisted, winged self-righting

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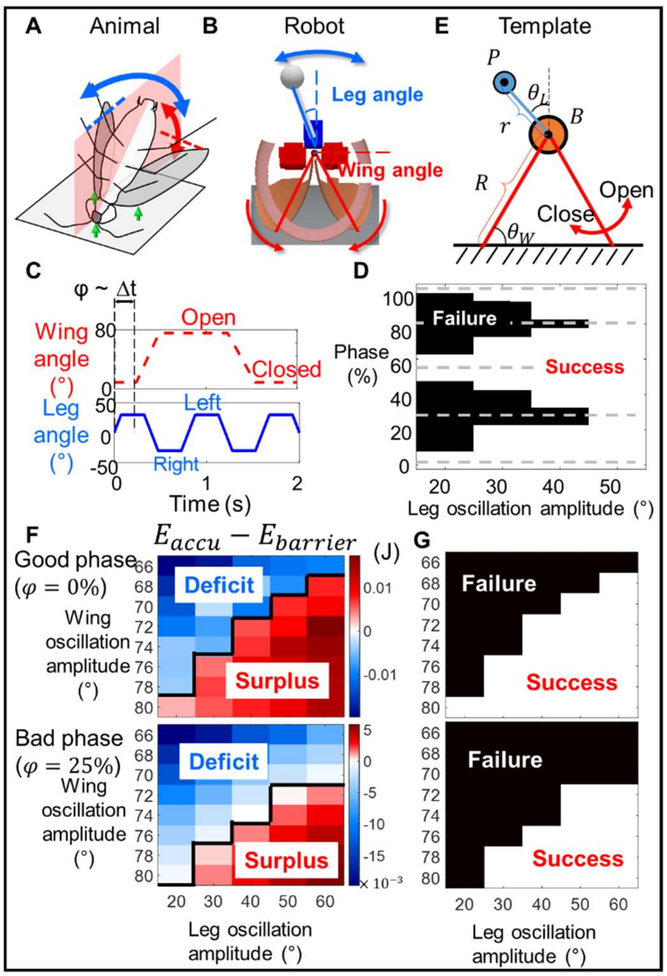
I. Introduction

Animals and mobile robots must right themselves when flipped over on the ground, a situation that is particularly likely during locomotion in complex terrain [1]. Winged insects like many cockroaches can push their wings against the ground to right. However, because this is a strenuous maneuver, the animal often fails to do a somersault and must make multiple attempts. Curiously, the animal often flails its legs to generate lateral perturbation to self-right [2] (Fig. 1A). Thus, the coordination between wing pushing and leg flailing affect self-righting performance.



II. Methods & Results

To understand the principles of leg-assisted, winged self-righting, a cockroach-inspired simulation robot (Fig. 1B) was developed (and validated against a physical robot experiment) to perform systematic simulation experiments [3]. The simulation robot has two wings that open symmetrically and a pendulum-like leg that flails laterally (Fig. 1B). Wings and leg are controlled to follow simple, periodic actuation profiles (Fig. 1C). Wing and leg coordination is measured by the phase φ between the two oscillations. Using simulation experiments, we discovered that self-righting was more successful at some phases (e.g., φ = 0%, 50%, and 100%, "good phases") than others (e.g., φ = 25% and 75%, "bad phases") (Fig. 1D).

To elucidate the mechanism of how phase affected self-righting outcome, we developed a template to model the complex dynamics resulting from hybrid contact and discontinuous actuation (Fig. 1B, C). For simplicity, our template only models planar dynamics of the robot in the transverse plane (Fig. 1E). The mechanical energy of the model changes with time during self-righting in complex ways, as (1) wing and leg motors doing positive work and (2) wing tip collision with the ground and wing and leg motor stopping dissipate energy. We used the template to calculate mechanical energy budget (Fig. 1F)—how the cumulative mechanical energy compares with potential energy barrier to self-right (both as a function of time). If there is a surplus, self-righting succeeds; otherwise, self-righting fails. Our energy budget from the template well predicted self-righting outcome (Fig. 1F, G) and revealed that the system is more likely to self-right at good phases because it accumulates more mechanical energy.

III. Future Work

Because the template is predictive, we can apply it for model-based robot design, control, and planning. In addition, we can develop anchor models based on the template by adding more realistic morphology and actuation to better understand more complex self-righting strategies. For example, we can add an asymmetric weight into the system to mimic the effect of twisted and bended abdomen that the animal displayed during self-righting and further study the coordination of wings, legs, and body.

References

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