Internal actuators and parametric oscillations in unconventional robotic locomotion

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Abstract. Unconventional means of actuation and modes of locomotion in robot can be achieved via the periodic motion of internal degrees of freedom. Such internal actuation when coupled with other mechanics can produce motion in a variety of physical settings, from fast fish-like swimming motion in water or terrestrial motion when coupled with nonholonomic constraints to fast motion of soft robots. The talk will present results on the nonlinear dynamics of such motion.

Introduction

Mobility in robots is usually achieved by a few common means; with a few exceptions these are wheels or legs in ground robots, propellers in flying robots, articulated tails or fins and propellers in swimming robots. However less explored is the means by which internal actuators or degrees of freedom, that do not directly interact with the environment, produce locomotion. Periodic motion of an internal body such as a rotor can produce a variety of gaits. This is demonstrated in four different settings. In the first, periodic oscillations of an internal rotor inside a nonholonomic system, a Chaplygin sleigh, leads to limit cycles in a velocity space and a serpentine motion of the Chaplygin sleigh [1]. When the body has an additional passive tail, these limit cycles can undergo bifurcations resulting in different gaits [2]. In the second example the oscillations of a rotor inside a Joukowski foil submerged in water creates a reverse Karman wake and leads to fish-like motion [1]. In the third example, high frequency internal vibrations enable a small body with bristles to propel itself due to stick-slip motion or climb pipes and navigate a pipe network. In the last example, oscillations of an internal rotor enables a body to jump. While the mechanics of the four examples differ, the common theme is that of the motion of internal degrees of freedom.

Results and Discussion

The findings from the first two examples, is that fish-like swimming can be modeled as a nonholonomic system subjected to periodic excitation. Building on the work in [1] and [2], it is shown that the propulsion speed has a complex dependence on the frequency-amplitude of the excitation. Further more the periodic excitation, which leads to periodic yaw motion of the body submerged in water, then couple parametrically to the roll oscillations of the body. It can be shown that the swimming body becomes roll unstable for some frequency-amplitude yaw oscillations, in a manner that is similar to that of the Mathieu oscillator, suggesting trade-offs in speed-agility vs stability for underwater robots. More interestingly the addition of passive appendages on a fish-like robot not only confers the ability to achieve different gaits, but also allows embodied sensing of hydrodynamic wakes based purely on the kinematics of the passive tail. In the third example a body with bristles containing a vibrational motor propels itself due to the slip motion enabled by parametric resonant oscillations. In [3] it was shown that such a system can be modeled by a Mathieu oscillator with slip dynamics. In more recent work it is demonstrated that for a soft robot with a vibrational motor, which can be modeled by a Hill's equation, parametric oscillations when in an unstable regime enable the soft robot to navigate a pipe network or climb pipes. In the last example, fast internal motion of a rotor inside a soft or a rigid body produces jumping motion. The four examples demonstrate the versatility of motion that is possible through internal actuators.

References

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