Exploiting Friction for the Locomotion of a Hopping Robot

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Compared to artificial locomotive systems, animals are capable of remarkable adaptive locomotion in an unpredictable environment. An interesting aspect is that, for the locomotion purposes, biological systems adaptively take advantage of the friction between the ground and the contact points of their body. Moreover the use of such a locomotion mechanism covers a wide variety of species in nature, from worm/snake style locomotion to shuffling locomotion of legged-animals. In this paper, we investigate how the friction between a system and the ground could be exploited for the purpose of locomotion. At first, we propose two conceptual working hypotheses particularly focusing on two important issues, (1) how to control the friction to increase the stability of a locomotive system, and (2) how the friction could mobilize a system for a form of adaptive locomotion.

Based on these conceptual design principles, we have developed a robotic platform “Stumpy” shown in Figure 1. The morphology of the Stumpy robot consists of two ”T” shape components, called ”upper body” and ”lower body”. The Stumpy robot’s lower body is made of an inverted “T” mounted on wide springy feet. The upper body is an upright “T” connected to the lower body by a rotary joint providing one degree of freedom in the frontal plane. This enables the upper body to act as an inverted pendulum. The horizontal beam of the upright “T”, is weighted on the ends to increase its moment of inertia. It is connected to the vertical beam by a second rotary joint, providing one rotational degree of freedom, in the plane normal to the vertical beam of the upper “T”. Stumpy is controlled to move in a unique way by actuating its waist joint, with a right and left swinging motion. This motion of the upper body provides angular momentum to the base which creates a rhythmic hopping motion. The second motor which is equipped in the shoulder joint is also controlled in a oscillatory manner, which provides momentum to drive the robot in horizontal plane.

In the first set of experiments, we conduct a series of behavior analysis, where we investigate two basic behaviors of the Stumpy by using the waist actuation, i.e. “hopping” and “lateral bounding”. In these analyses, we perform comparative studies of these behaviors in two different terrains which have different coefficients of firction. The main conclusion is that the experimental results statistically show that the slippery interaction between the robot and the ground could increase the stability of the locomotion. Another interesting results from these analysis is that, by using a simple 1-DOF inverted pendulum oscillation, Stumpy shows 6 qualitatively different behaviors in one dimensional lateral locomotion, which are controlled by 4 partially coupled redundant parameters, i.e. friction coefficient, amplitude, frequency and the set point of the oscillation. This variety of behaviors might enhance the adaptability of a locomotive system. For instance, the ipsilateral bounding is faster and more unstable than contralateral bounding. Therefore, the ipsilateral behavior could be used for emergency situation. The contralateral one is, on the other hand, stable and robust which can be viable for practical long-term applications.

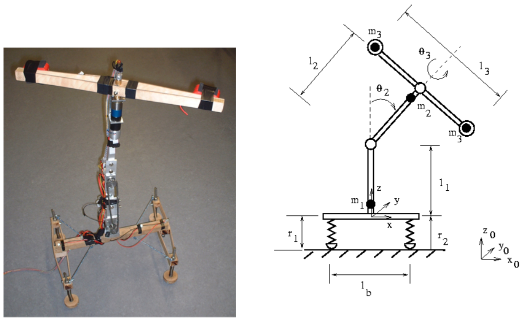

Figure 1: The Stumpy robot

Moreover another set of experiments demonstrate how this robot could be used for a practical application. In these experiments, we show a way to change the direction and the turning rate of the locomotion, which could allow the robot to explore a two-dimentional terrain.

A criticism to what we discuss in this paper might be whether it is worth exploring all the possible locomotion behaviors exploiting the slippery interaction between a system and the ground, since the energy efficiency of locomotion is always lower with respect to traveling distance as long as there is a friction force. However, our interest of this research is not only to focus on the efficiency, rather we are interested in a comprehensive understanding of adaptive locomotion, where a repertoir in locomotion behavior, we believe, plays an important role.