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Control of a Cheetah Robot in Passive Bounding Gait

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Abstract

Passive dynamics is always one of research emphases of the legged robots. Studies have proved that cheetah robot could achieve stably passive bounding motion under proper initial conditions in the ideal case. However, the actual robot must have energy dissipation because of friction and collision compared with the theoretical model. This paper aims to propose a control method that can drive the cheetah robot running in passive bounding gait. First, a sagittal-plane model with a rigid torso and two compliant legs is introduced to capture the dynamics of robot bounding. Numerical return map studies of the bounding model reveal that there exists a large variety of passively cyclic bounding motions (fixed points). Based on the distribution law of fixed points, an open-loop control method including touchdown angle control strategy and leg length control strategy is put forward. At last, prototype of the cheetah robot is designed and manufactured, and locomotion experiment are carried out. The experiment results show that the cheetah robot can achieve a stable bounding motion at different speeds with the proposed control method.

Keywords: cheetah robot, passive dynamics, control, bounding gait

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1 Introduction

Bionic quadruped robots have been rapidly developed for decades because they show advantages in moving speed and complex environment adaption than wheeled and tracked robots. Early developed quadruped platforms such as Aibo[1], BISAM[2], Tekken[3], TITAN[4] and LittleDog[5] were slow moving and statically stable robots. Recently, more researchers focus on cheetah robots[6–8] which could achieve a high-speed running. Our attention is restricted to the control method of dynamically stable cheetah robot.

At present, there exist two effective controllers to drive the cheetah robot. The first one is the controller based on Spring Loaded Inverted Pendulum (SLIP) model[9]. The well-known SLIP model for legged locomotion is proposed from biomechanical, as it is very effective in the description of dynamic behaviors of many kinds of animals. Raibert's landmark work[10] can be seen as a great extension of this idea. Raibert *et al.*[11] proposed a three-part controller which could be used to control one-, two-, and four-legged robots. Besides the work by Raibert *et al*, many other controllers[12–14] have been proposed based on SLIP model. The other one is the controller based on Central Pattern Generator (CPG)[15]. The CPG imitates the nerve system of the animal and can produce rhythmic movements to control robot. CPG related approaches[16–18] have been studied by many researchers and applied to control robots locomotion with different gaits and speeds.

Although these controllers can achieve stable motion of the robot, they all have certain limitations in the aspect of bionics. The SLIP controllers need state feedback to plan the next stride motion. The CPG controllers need to calculate the connection parameters in the CPG network depending on experimental regulation. Research showed[19] that the biological system had a mind of its own, rather than governed by the nervous system especially when the suggestions from nervous system were reconciled with the physics of the system and task. This is to say the movement of animal doesn't need feedback and high-level command and the move-

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ment of the mechanical system should be like this too. To simplify analysis, the planar quadruped model with rigid torso and two massless legs was used to research. Raibert *et al.*[20] studied this model and found that the system could run passively without any control when a dimensionless moment of inertia of the robot is less than unity. Neishtadt and Li[21] and Berkemeier[22] utilized mathematic analysis to prove and enrich Murphy's results. Furthermore, Poulakakis *et al.* [23] found that the two variations of the bounding gait which had been experimentally observed on Scout II, could be passively generated with appropriate initial conditions based on the analysis of numerically derived return maps. However, Poulakakis only studied the control strategy of touchdown angle, since Scout II that adopted telescopic/prismatic leg design had only one active joint in each leg. He ignored the leg length control which played a key role in stabilizing roll-angle and pitch-angle movements.

The goal of this paper is to propose an open-loop control method including touchdown angle control strategy and leg length control strategy which could drive our cheetah robot running in passive bounding gait. In section **2**, the mechanical design of the Huazhong University of Science and Technology (HUST) cheetah robot is presented. Passive dynamics of the HUST cheetah robot are studied in section **3**. In section **4**, an open-loop position control method is proposed based on the analysis of fixed points. Furthermore, the control method is implemented with the HUST cheetah robot in section **5**. The final conclusion and possible future research are discussed in section **6**.

2 Mechanical design of the HUST cheetah robot

In the biological world, cheetah is undoubtedly the best template of our research. Its speed can reach up to 33 m·s^{-1}. The HUST cheetah robot is designed according to the skeletal structure of cheetah, which could be simplified to a three-segmented mechanism in Fig. 1b. However, as motors are directly mounted on joints in the mechanism of Fig. 1b, mass and inertia of the leg are large, which limit the moving speed of the legged robots. Reducing the mass of the leg and introducing compliance are the keys to increase the speed of the robot. Based on these two points, three mechanical improvements are proposed. First, all motors are mounted on the body of the robot to reduce the mass of legs. Second, a parallel four-bar linkage is added to couple knee joint and ankle joint, since two active Degrees of Freedom (DOFs) are sufficient for the end to reach any position in the plane. Third, spring is designed to reduce leg stiffness. The leg configuration of HUST cheetah robot is shown in Fig. 1c.

The dimensional model of the HUST cheetah robot is depicted in Fig. 2. The robot's legs are each actuated by hip Radio Control (RC) servo motor and knee RC servo motor, both of which have different functions. Hip motor connected with femur through flange, directly drives the leg swing forward and backward. Knee motor and tibia connected to the both ends of the cable mechanism which is composed of cable, cable wheel and

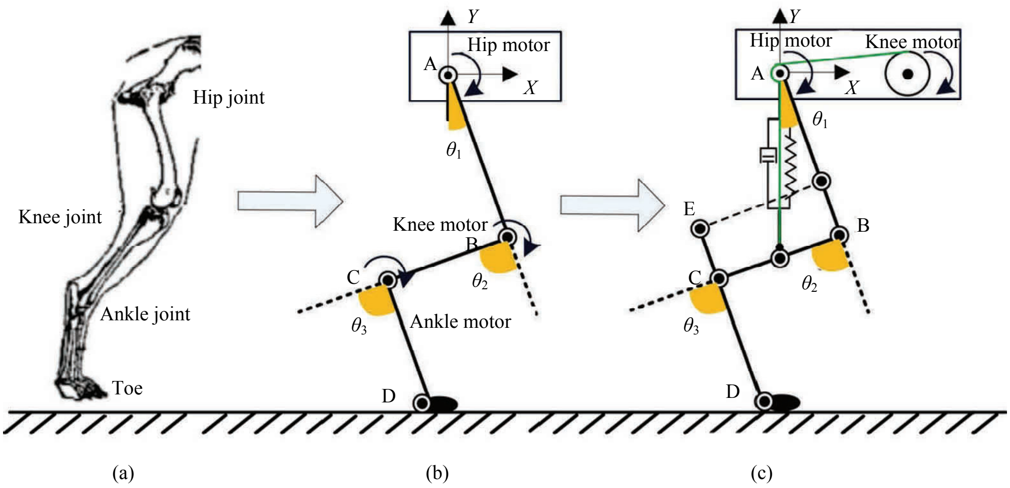

Fig. 1 (a) Leg configuration of animal; (b) leg configuration of quadruped robot; (c) leg configuration of cheetah robot.