Cheetah-inspired robot: design of a high speed galloping quadruped

Sangbae Kim

Department of Mechanical Engineering, Massachusetts Institute of Technology
(Tel: +1-617-452-2711; E-mail: sangbae@mit.edu)

Abstract: Legged robotics has drawn much attention from robotic researchers due to its versatility over wheeled systems in non-smooth terrain. Despite recent advances in a range of technologies, the realization of agile dynamic locomotion remains as a difficult challenge. High power requirement and control of fast dynamics attributes the difficulties. The multidisciplinary nature of the design task, in addition, compounds the difficulties. We present the cheetah robot project and address three major challenges associated with developing a high-speed running quadruped. The challenges include high torque density actuator development, lightweight, robust structure fabrication, and hierarchical control architecture. We extensively observe fast running animals to obtain insights and guidelines in various aspects ranging from the body level dynamics to the foot structure details. From the observation of cheetahs, we hypothesize the influence of active body articulation in high speed running. Another hypothesis drawn from cheetahs is that active tail not only helps to reject disturbances in steady state running but also improves agility in changing direction.

Keywords: Selected keywords relevant to the subject.

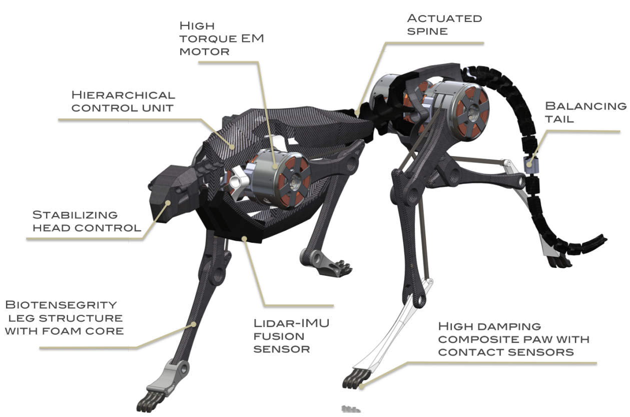

Fig. 1 The solid model of the cheetah-inspired running platform under construction.

1. APPROACHES

The presentation addresses three major challenges and corresponding strategies in developing a high speed running robot.

1.1 High torque density actuators

The actuators often limit the performance of legged robots since torque/force density of conventional actuators are substantially lower than biological muscles, while electromagnetic motors and internal combustion engines achieve high power density at high speed. These high speed actuators require high gear reduction to generate high torque at the joint of the leg. The high gear reduction increases the weight of the robot and the high reflected inertia from the high gear reduction prevents high bandwidth impedance control. This is a typical case found in many legged robots.

This problem can be mitigated by carefully selecting a motor size. A large radius motor has a high rotational inertia but requires less gear reduction due to its high torque density; torque density is proportional to the radius of the gap between the stator and the rotor. Another aspect of motor characteristics considered is the thermal mass. Unlike factory robots, the duty factor of the motor usage is much lower in legged robots. A momentary recovery action may requires high current yet only for a short period of time not in a regular fashion. In order to utilize the maximum capability of the motor preventing from thermal failure, utilizing temperature information of the coil is essential. Also, higher thermal mass of the motor lengthen the time of high torque operation and slows the thermal dynamics for safety.

1.2 Lightweight and robust structure

For a highly dynamic platform, the properties of the structure can play an important role in running performance. High speed running requires high ground reaction forces as duty factor, the ratio of the ground phase to the airborne phase and high acceleration of the leg. This entails difficulties in structure design of the leg. Since the weight of the robot determines stresses upon impacts caused by regular locomotion or failures, lightweight structure is critical as well as the compliant structure. We employ a bio-inspired design principle called 'biotensegrity' which allows lightweight and robust structure combined with compliances. As an implementation of this principle, we introduce a new rapid prototyping technique that allows foam-core-hard-shell structure combined with embedded tendon materials.

1.3 Hierarchical control architecture

The third challenge is to develop a hierarchical control architecture. The primary control strategies are as follows:

- Decoupled plenary dynamics: unlike bipeds, the stance quadruped running stance is narrow and long. With an assumption that the sagittal plane dynamics can be mostly decoupled from frontal one in straight running, we can develop each control algorithms independently and merge them.

• Hierarchical controller development: the body level controller and leg level controller will be developed in parallel to reduce the complexity of the dynamics in high level planning. The model will be divided at the shoulder joints as force ports. The body level controller will perform a 'gait planning' assuming that each leg can deliver a 'commanded' force profile. Port force mapping tool: the tool will be developed to provide a force generation capability of the leg in space at given running speed, including the leg dynamics, the friction cone constraint, and the actuator torque limit. This tool will guide the design of the controller providing the estimation of the force profile to the body level controller.