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Quadruped leg design principles for handling slopes or high-speed running

Ioannis Kontolatis and **Evangelos Papadopoulos**

School of Mechanical Engineering
National Technical University of Athens
9 Heroon Polytechniou Str., 15780 Athens, Greece
[ikontol, egpapado]@central.ntua.gr

Abstract

Humans and animals have incredible motion capabilities in terms of speed, energy efficiency and capacity for transversing environments with extreme slopes. These capabilities are due mainly to their legged locomotion system that allows them to use discrete footprints in handling terrain discontinuities. Also, they modify muscle stiffness and center of mass (CoM) location to preserve their desired motion in an efficient way, despite ground inclinations. In addition, humans and animals are able to perform dynamically stable motions, so as to achieve high speeds.

Engineers have already acknowledged the potential advantages of legged locomotion, and presented leg concept designs that address technical issues. In [1], the robot FastRunner utilizes a leg architecture, which incorporates a network of elastic elements and uses a single main drive actuator as a power source. Ananthanarayanan et al. in [2] applied to leg design the hypothesis that employing a tendon-bone co-location architecture not only provides compliance in the leg, but can also reduce bone stresses caused by bending on structures. In [3], Hutter et al. introduce and compare two compliant robotic legs that perform precise joint torque and position control, that enable passive adaptation to the environment, and that allow for the exploitation of natural dynamic motions. Semini et al. designed an articulated/ segmented leg, suitable for a versatile robot that runs, hops and navigates over rough terrain [4]. In [5], Kontolatis et al. have shown that an optimum region of leg spring constant and uncompressed length emerges for level and sloped (positive/ negative) terrain traversal.

Although these research works have concluded with proof of concept results, they do not offer specific guidelines about leg design options. To the best of our knowledge, no comparison between alternative leg designs has been performed so far. Taking this into consideration, in our current work we perform multibody analysis and conduct simulations using the Matlab and MSC Adams software to define guidelines for two fundamental aspects of leg design.

Design Aspect 1

The question to be addressed here is: which is the optimum knee joint orientation for a quadruped robot that traverses straight-ahead (a) a sloped terrain and (b) a level terrain at maximum speed? Fig.1 displays some of the possible answers to this question.

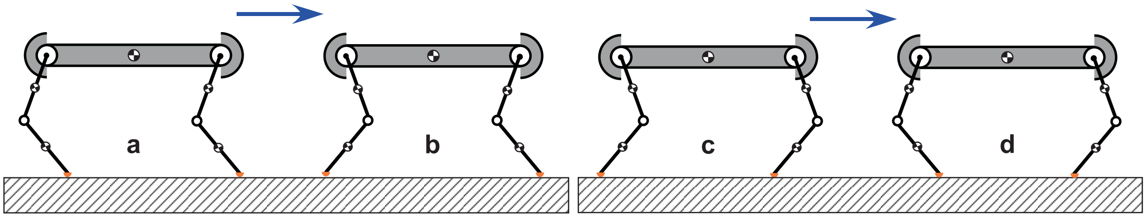

Figure 1: Knee joint orientation design options. (a) Both backwards, (b) Rear frontwards-Front backwards, (c) Both frontwards and (d) Rear backwards-Front frontwards.

Design Aspect 2

Which is the optimum degree of freedom (DOFs), actuated DOF and compliance elements position for a quadruped that traverses straight-ahead (a) a sloped terrain and (b) a level terrain with the maximum speed? Fig. 2 displays some of the alternative designs that can be considered.

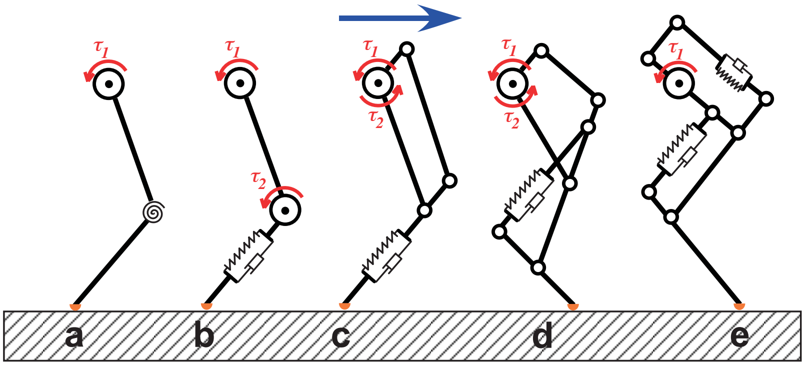

Figure 2: Leg architecture options. a) One actuator (hip), torsion spring (knee), b) Two actuators (hip, knee), linear spring (ankle), c) Two actuators (hip), 4-bar link, linear spring (ankle), d) Two actuators (hip), two 4-bar links, linear spring (ankle) and e) One actuator (hip), two 4-bar links, linear spring (ankle).

These two leg design questions are answered taking into consideration the following design goals for both sloped terrain and high-speed level terrain motion:

- low suspended mass
- low energy consumption
- adequate traction to achieve maximum motor torque exploitation
- impact and torsional load durability

For effective leg design, two more points are taken into consideration; for high-speed running, all legs should oscillate in high frequencies and be able to perform large angle trajectories in the sagittal plane, while during sloped terrain motion, the legs should be able to move in both the sagittal and coronal planes.

At ECCOMAS 2015, we will present the latest results and conclusions towards answering these questions, and will provide guidelines for leg design as it is affected by the need for slope handling and for high-speed performance.

References

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