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ScienceDirect
Journal of Bionic Engineering 12 (2015) 339–351

# Effect of Hind Leg Morphology on Performance of a Canine-inspired Quadrupedal Robot

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**Abstract**
Biomimetic leg designs often appear to be arbitrarily chosen. To make a more objective choice regarding biomimetic leg configuration for small canine-inspired robots, we compare one hind leg to the same leg arranged in a different orientation, and show that the less biomimetic leg provides better performance. This differently-oriented leg design, which we call "transverse-mirrored" was more efficient and faster, both in simulation and experiment even though both leg configurations used the same passive and active components, rest angles, and monoarticular knee spring. In experiments the normal configuration had a maximum speed of 0.33 m·s$^{-1}$ and a specific resistance of 5.1. Conversely, the less biomimetic transverse-mirrored configuration had a maximum speed of 0.4 m·s$^{-1}$ and specific resistance of 3.9. Therefore the transverse-mirrored leg's best performance yields a 21% increase in speed and 24% decrease in specific resistance when compared to the best performance achieved in the normal biomimetic leg. The major underlying reason is that the knee spring engages more readily in the transverse-mirrored configuration, resulting in this faster and more efficient locomotion. The conclusion is that simply copying from nature does not lead to optimal performance and that insight into the role played by passive design components on natural locomotory dynamics is important.

**Keywords:** biomimetic, legged robot, quadruped, leg design, walking, legged locomotion


doi: 10.1016/S1672-6529(14)60126-8

## 1 Introduction

Biologists and biomechanicists have speculated on the effect that leg joint direction plays on the dynamics of locomotion, but validating theories on animals would be difficult or impossible. Unfortunately, roboticists working on bioinspired legged robots have had the opportunity to explore this issue but have, instead, often typically made arbitrary choices when it comes to leg joint direction designs, with potentially significant effects on the robot's natural dynamics[1–4]. Typically, a designer examines a biological leg and extracts a simplified topology as the focus for robot design, such as that seen in Fig. 1. For instance, many robots have been designed with posterior-pointing knees, including Tekken[5], the Jena Hopper[6], KOLT[7,8] and Pfeifer and Iida's quadruped[9]. The Boston Dynamics BigDog has alternated the knee directions[10], without explanation. In monopods it is possible that leg shape, and in particular a bow-like shape, can reduce limb stiffness and leg force[11]. The quadrupedal Biosbot, with two-segment legs and reconfigurable knees[12,13] initially attempted to examine the effect of knee direction on gait performance in a quadruped but the results were insufficiently detailed to draw meaningful conclusions. In contrast, this paper presents, for the first time, detailed simulation and experimental evidence for how the knee direction of a hind leg influences the robot's natural dynamics and subsequently the performance of a walking gait. In short, we find that an inverted leg configuration yields higher speeds and improved energy efficiency.

This work stands out from other studies in leg robotics in the comparisons between simulation and experimentation in legged-robotics studies (*e.g.* Refs. [14–19]) which are rare within the robotics community. Typically, either only experimental results are given, (*e.g.* Refs. [9, 20, 21]) or only simulation results, (*e.g.* Refs. [22–25]) but not both. Given that qualitatively similar results are found both in simulation and experiments of this study we are confident that the improved

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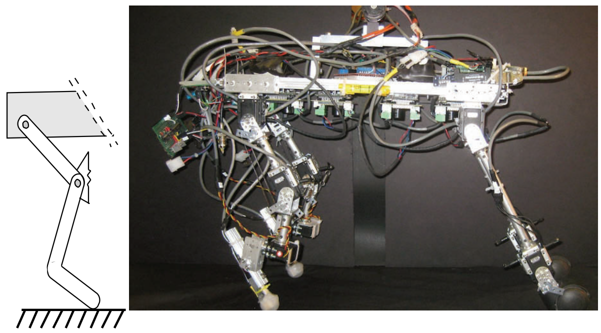
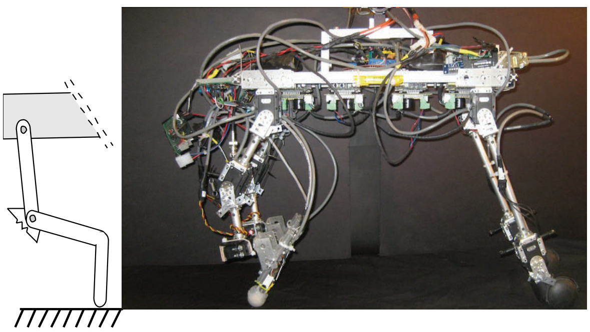


(a) Normal hind leg



(b) Transverse-mirrored hind leg

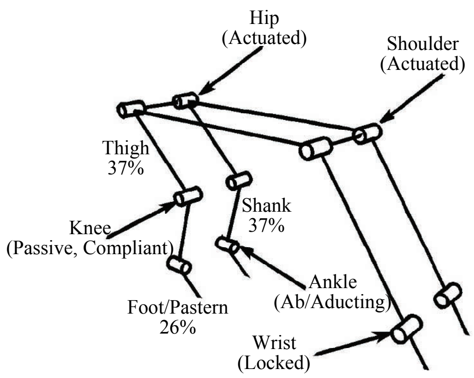
**Fig. 1** The GARP-5 robot in the (a) normal and (b) transverse-mirrored hind leg configurations.

performance observed using the inverted leg configuration is valid.

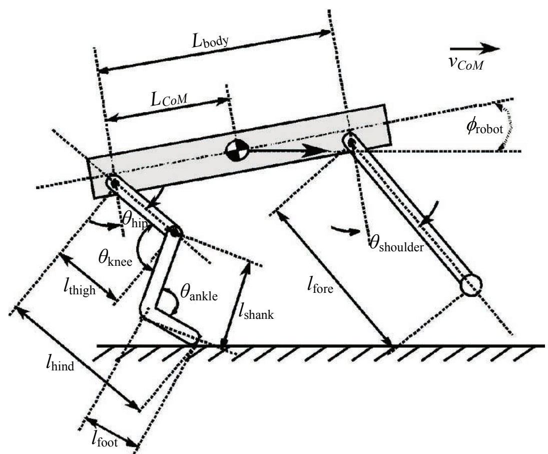
## 2 GARP-5's canine-inspired design

The main objective of this study is to quantify the difference in robot walking performance resulting from varied hind leg configurations. Specifically, we examine the effect played by having knees pointing posteriorly compared to posteriorly on the same bioinspired quadrupedal robot.

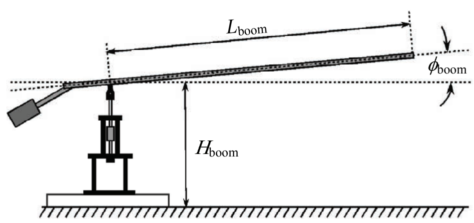
The GARP-5 robot, with an effective mass of 1.56 kg, is supported by a boom, shown in Fig. 2. The boom's mass is 1.1 kg, and its counterweight is 6.72 kg. It is common practice for experimental legged robotics to be supported or constrained by booms in order to study the movements of the robot. Booms are used to support the robot in two ways: by allowing the robot to rotate in a circular path of a fixed diameter (rotational booms) or keeping the robot in one spot, such as jumping up and down, or walking on a treadmill (stationary booms). Robots that use rotational booms include Cheetah[26], Raibert's monopod and biped robots[27], Thumper and MABEL robots[28], RABBIT[29], and Run Bot[30]. Robots that are supported by stationary booms include the Jena Walker[31], KOLT[8], and Ernie[32]. The boom was configured to gather angle/position data but not reaction force or torque data.




(a) Limb proportions




(b) Important variables




(c) The boom

**Fig. 2** Important robot geometry and canine-inspired limb proportions in (a) and (b). The angle for the ankle is 131˚, while the knee rest angle is 142˚. The boom's variables are shown in (c).