Comparing the effect of different spine and leg designs for a small, bounding quadruped robot

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1 Introduction

We present Lynx-robot, a quadruped, modular, compliant robot. It features an either directly actuated, single-joint spine design, or an actively supported, passive compliant, multi-joint spine configuration. This study aims at characterizing these two, largely different spine concepts, for a bounding gait and a robot with a three-segmented, panthographic leg design (ASLP-leg [1]). The Bobcat-robot [2], a similar-sized, bounding, quadruped robot with a two-segment leg design and a directly actuated, single-joint spine design serves as a comparison. The following hypotheses (among others) were tested: (1) The cost of transport (CoT) for a bounding gait is different for two spine-designs with equal morphology, but different spine stiffness. Typically, we expect a lower cost of transport for a moderately lower spine stiffness. (2) The leg design influences the cost of transport: we expect a lower CoT for the more bio-inspired, three-segment, panthograph leg design (Cheetah-cub like [1]), compared to the simpler, two-segment leg design of Bobcat-robot [2]. (3) The passive interaction between the environment and the robot due to in-series compliance of the spine contributes positively in achieving stable, open-loop locomotion-patterns like shown in [3, 4].

2 Experimental platform Lynx-robot

Lynx is a lightweight robot with 9 degrees of freedom (DOF), two per leg (based on the Cheetah-cub leg design [1]) and one in the spine. It consists of two trunk segments, the legs and an active spine that connects the trunk elements.

Table 1: Hardware characteristics of Lynx-robot, spine version SV1, SV2, and SV3.

Parameter	Value
Mass	1.2 kg
Standing height	0.154 m
Width	0.132 m
Length	0.224 m (SV1) 0.226 m (SV2) 0.225 m (SV3)
RC servo motor	Kondo KRS2350 ICS (9x)
Control board	RoBoard RB110
Communication	Wifi card Via VT6655

The 3 spine versions implement different mechanisms with a decrease in abstraction from nature (SV1 high, SV2 and SV3 lower, see Fig. 1). The design is completed by a totally passive tail-like structure, that acts like a 5th-leg-stabilizer of the system in case of high pitching motion (it prevents the robot from falling backwards). The control of Lynx is realized through a parametrized, fully connected CPG-network with forward kinematic implementation [1] running on board. Lynx-robot's CPG network consists of nine nonlinear oscillators (hip, knee for each leg and one for the spine) and although possible does not include any feedback (open-loop).

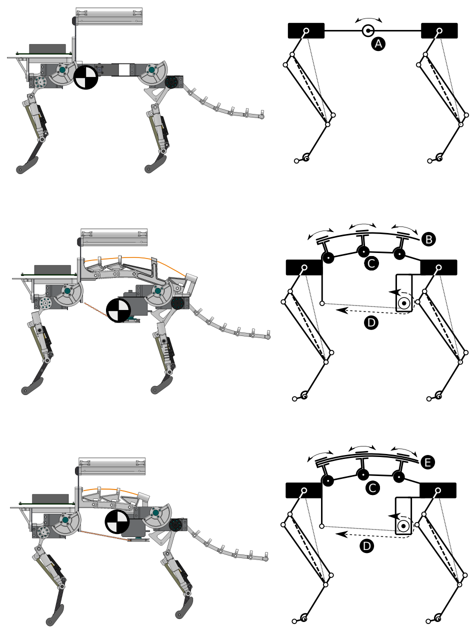

Figure 1: Lynx-robot from top to bottom: SV1, SV2, and SV3. Markers indicate the center of mass. (A) Single, rotatory, actuated joint. (B) Single leaf-spring, pre-stressed. (C) Multiple, passive, rotatory hinge joints with limited range of rotation: only downwards. (D) Antagonistic actuation based on pulley and cable mechanism (flexing-torque in SV2/SV3, External flexing: the cable mechanism goes slack). (E) SV3: two glass-fiber leaf springs in-parallel.

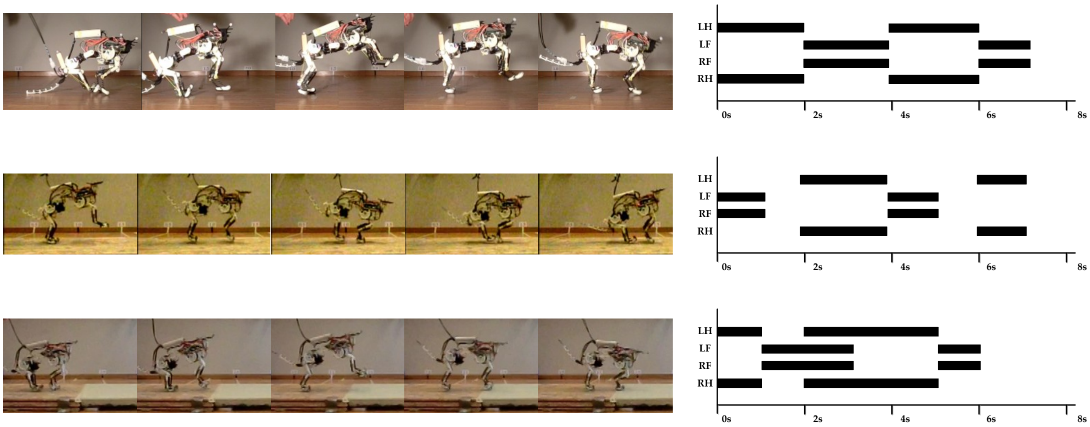

Figure 2: Representative bound-gait snapshots (left) and corresponding footfall-patterns (right); from top to bottom (SV1, SV2, SV3). **SV1**: $v = 0.75\,\mathrm{m/s}$, SV1 is the only configuration that required stabilization in pitch-rotation, trough its tail-like structure preventing falling backwards (visible in the first snapshot), real Duty-factor $DF_{av} = 0.5$. **SV2**: $v = 0.6\,\mathrm{m/s}$, and no ground contact of its tail-like structure, real Duty-factor $DF_{av} = 0.4$. **SV3**: $v = 0.6\,\mathrm{m/s}$, no ground contact of tail-like structure, real Duty-factor $DF_{av} = 0.625$.

3 Results and Discussion

In terms of CoT the Lynx SV1, SV2 and SV3 differ not significantly one from another (see Table 2). Keeping this in mind, we *cannot* confirm hypothesis 1. All spine-versions reach much lower CoT-values than Bobcat. This decrease of CoT in the active spine gait, although the mass of the robot is increased ($\approx 0.17kg$), is due to the advantages in passive compliant movement the ASLP-leg provides in contrast to a two-segmented leg and thus validates hypothesis 2. The spine of SV1 is identical to the one used for Bobcat and enables the ideal comparison of the symbiosis from leg and spine.

Table 2: Speed (first speed, second Froude-Number) and CoT comparison of the best gaits in all version with respective Bobcat-gait (data taken from [2]).

	Bobcat	Lynx-SV1	Lynx-SV2	Lynx-SV3
Speed $\left[\mathrm{m\,s^{-1}}\right]$	0.78	0.75	0.6	0.6
Froude-Nr []	0.5	0.25	0.24	0.24
Cot $\left[J\,Nm^{-1}\right]$	10.9	3.9	4.9	4.7

The spine versions 2 and 3 are $\approx 21\%$ slower than SV1, $\approx 25\%$ and slower than Bobcat. That results in a Froude-Nr for Lynx that is half the one of Bobcat. The difference in speed is due to the use of a different spine architecture with higher elasticity. The shift from a single, to a multi-rotation point of the spine provided more stable locomotion. As shown in Fig. 2 the multi-segmented spines, with the right level of stiffness, seem to enable the robot to move more with bound-characteristics found in literature, such as flight-phases in the footfall-pattern as well as pitch stability (confirming hypothesis 3). The single-rotation spine in SV1 thus might be too strongly abstracted from the long-spined animal role models. Although SV3 shows comparable results in the top speed, it differs in the observed characteristics of the gaits in SV2. The reason for this might be the slower reaction time of the spine, due to higher spine-stiffness, and the resulting delay in the flexion of the spine.

Acknowledgement

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4 Presentation format

We like to present our work in form of a short talk.

References

[1] A. Spröwitz, A. Tuleu, M. Vespignani, M. Ajallooeian, E. Badri, and A. Ijspeert, “Towards Dynamic Trot Gait Locomotion—Design, Control, and Experiments with Cheetah-cub, a Compliant Quadruped Robot,” *The International Journal of Robotics Research*, vol. 32, no. 8, pp. 932–950, 2013.

[2] M. Khoramshahi, A. Spröwitz, A. Tuleu, M. Ahmadabadi, and A. Ijspeert, “Benefits of an Active Spine Supported Bounding Locomotion With a Small Compliant Quadruped Robot,” in *Proceedings of 2013 IEEE International Conference on Robotics and Automation*, 2013.

[3] M. Hildebrand, “Analysis of asymmetrical gaits,” *Journal of Mammalogy*, vol. 58, no. 2, pp. pp. 131–156, 1977.

[4] ——, “The quadrupedal gaits of vertebrates,” *BioScience*, vol. 39, no. 11, pp. pp. 766–775, 1989.