How Quadrupeds Benefit from Lower Leg Passive Elasticity

Felix Ruppert and Alexander Badri-Spröwitz
Dynamic Locomotion Group
Max Planck Institute for Intelligent Systems, Stuttgart, Germany
{*Ruppert, Sprowitz*}@*is.mpg.de*

Recently developed and fully actuated, legged robots start showing exciting locomotion capabilities, but rely heavily on high-power actuators, high-frequency sensors, and complex locomotion controllers. The engineering solutions implements in these legged robots are much different compared to animals. Vertebrate animals share magnitudes slower neurocontrol signal velocities [1] compared to their robot counterparts. Also, animals feature a plethora of cascaded and underactuated passive elastic structures [2].

We are especially interested in passive elastic structures found in animals' lower legs, and their potential functional benefits for walking machines. The control effort of robots equipped with passive and elastic leg structures can be drastically reduced [3, 4]. Yet, only a few such mechanisms are sufficiently explored and understood from a functional perspective.

We want to present our results investigating the role of biarticular elastic structures in a robotic, three-segmented leg [3]. We found that elastic structures modeling the lower leg muscle-tendon structures in quadrupedal mammals could reduce the locomotion power requirements of our robotic leg by 30 %, compared to a leg configuration without energy storage capacity from distally located, leg angle compliance. We recorded a cost of transport (COT) of 1.2 at 0.9 kg robot weight at $v = 1\,\mathrm{m/s}$ forward hopping speed. The robot leg's metabolic power consumption presents the currently lowest achieved relative cost of transport documented for dynamically hopping and running robots; at 64 % of a comparable natural (animal) runner's COT.

Related, we wish to present a novel sensor design to measure the center of pressure and ground reaction forces in a rugged and lightweight, soft sensor based on a barometric pressure sensor [5]. We expect that measuring the center of pressure will become especially important for robotic legs with digitigrade and plantigrade foot-like structures.

We are currently finalizing the integration of our robotic leg with its biarticular muscle-tendon structures into a quadruped robot (Fig. 1). During walking and running, passive and underactuated leg structures interact differently in a quadruped configuration, compared to an isolated hopping robot leg on a boom. Also, front and hind legs of quadrupedal animals differ in their morphology, i.e., in their length and segmentation. We are excited to characterize soon resulting and emerging quadrupedal robot gaits. Our future vision is to combine the advantages of feedback control [6, 7] with the benefits of mechanically compliant structures [3, 4] to reduce control effort and power requirements.

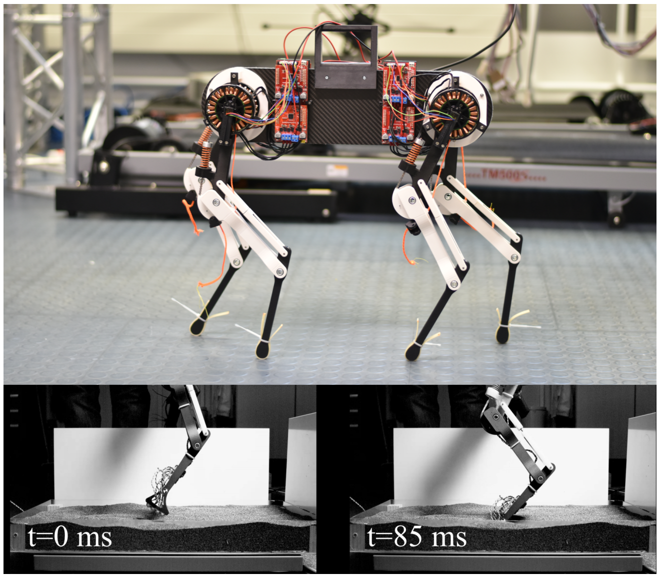

Fig. 1: Top: Quadruped robot Morti, with legs featuring mono- and biarticular springs mimicking the lower leg muscle tendon structures of quadrupedal animals. Bottom: our novel, all-terrain Foottile sensors measure center of pressure position of robot feet with a spacial resolution of 10 mm. Here shown is a leg-drop into granular media, in form of poppy seeds. Ground reaction forces can be extracted with high resolution and sampling frequency, and the sensors can be adapted for a large range of loads, and configurations. The light-weight and portable Foottile sensors will allow us to online-estimate changes of the center of pressure position in quadruped robots.

REFERENCES

[1] H. L. More and J. M. Donelan, "Scaling of sensorimotor delays in terrestrial mammals," *Proc. R. Soc. B*, vol. 285, no. 1885, p. 20 180 613, Aug. 2018.

[2] R. M. Alexander, "Three Uses for Springs in Legged Locomotion," *The International Journal of Robotics Research*, vol. 9, no. 2, pp. 53–61, Apr. 1990.

[3] A. Spröwitz, A. Tuleu, M. Vespignani, *et al.*, "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, Jun. 2013.

[4] F. Ruppert and A. Badri-Spröwitz, "Series elastic behavior of biarticular muscle-tendon structure in a robotic leg," *Frontiers in Neurorobotics*, vol. 13, p. 6, 2019.

[5] F. Ruppert and A. Badri-Spröwitz, "Foottile: A rugged foot sensor for force and center of pressure sensing in soft terrain," accepted to 2020 IEEE/RSJ International Conference on Robotics and Automation (ICRA), 2020.

[6] G. Bledt, M. J. Powell, B. Katz, *et al.*, "MIT cheetah 3: Design and control of a robust, dynamic quadruped robot," in *2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, IEEE, Oct. 2018.

[7] F. Grimminger, A. Meduri, M. Khadiv, *et al.*, "An Open Force-Controlled Modular Robot Architecture for Legged Locomotion Research," *RA-L, accepted to*, 2020.