Robust Walking using Piecewise Linear Spring

Mahdi Khoramshahi*, Ali Asaei*, Auke Ijspeert**, and Majid Nili Ahmadabadi*
* Cognitive Robotic Laboratory, University of Tehran, Iran
{*m.khoramshai, ali.asaei, mnili*}@*ut.ac.ir*
** Biorobotic Laboratory, EPFL, Switzerland
auke.ijspeert@epfl.ch

1 Introduction Having a direct impact on the energy efficiency has made the compliance a favorable element in the robotic systems. Moreover, legged system can benefit from compliance for stability, speed, adaptability and robustness. Recently, we have studied the effects of compliant spine in quadrupedal robots. We have observed that having nonlinearity in the spine compliance can set a better trade-off between speed and energy efficiency; see [1]. Similar to the spine in quadruped robots, compliance at the hip joint of bipedal robots can also improve the walking performance such as robustness; see [2]. Here, we test the efficacy of piecewise linear hip compliance for robust bipedal walking.

2 Passive curved-feet biped To test the effect of nonlinear spring further, we made a toddler bipedal passive robot (similar to [3]). The parts are inaccurate and the robot could not stably walk on a slope in its original form. We added two linear rotational springs between the legs on the free joint at the hip in a serial arrangement; a soft one with $k_s = 0.59 N.m/rad$ and one hard spring with $k_h = 0.8 N.m/rad$; see Fig. 1. The arrangement of springs is such that the softer one is always engaged while the hard spring is detached when the hip angle is between -8 and +8 degrees. This results in a piecewise linear spring at the hip joint.

3 Results We have tested the walking performance on a slope in four different conditions: with no spring, only with the soft one, only with the hard spring, and with the mentioned piecewise linear spring. Fig. 2 shows four frames of the robot walking passively. Each experiment starts with disturbing the robot from standing still. Every experiment is repeated several times and the average results are reported. The experiments are categorized in four groups: *OK*, *Damped*, *Stopped*, and *Unstable*. The *OK* category means the robot walks with a stable and regular gait one meter on the slope. *Stopped* tag is used if the robot suddenly stops after a few stable steps of walking. *Damped* means having short steps and stopping shortly after starting to walk. *Unstable* label is used when the robot gait becomes unstable and it falls down after a few steps of walking. Table 1 shows distribution of the experiments with respect to the defined categories. As the results show, the robot with no spring cannot walk stably while having spring at the hip joint enhances the robot stability. The nonlinear spring is superior in terms of stability – i.e. lowest (highest) percentage in *Unstable* (*OK*) category – as well as its walking distance.

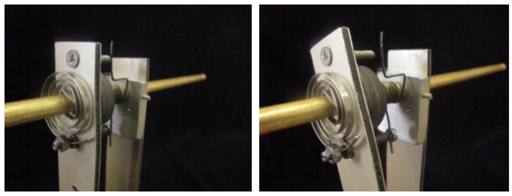

Fig. 1: The toddler robot with rotational springs at its hip joint

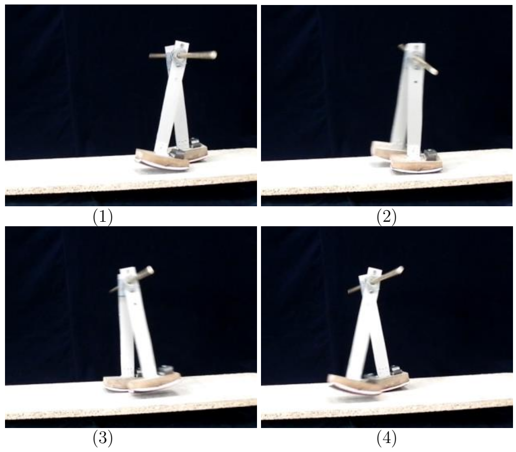

Fig. 2: Snapshots of the curved-feet passive walker on the slope.

Table 1: Gait performance for different types of compliance.

	OK	Damped	Stopped	Unstable
Non-compliant	0%	5%	30%	65%
Soft spring	11%	23%	31%	35%
Hard sping	43%	9%	19%	29%
Nonlinear spring	56%	17%	16%	11%

4 Future Work We will focus on more analytic approaches to design parallel compliance for legged systems.

References

[1] M. Khoramshahi, et al, *"Piecewise linear spine for speed-energy efficiency trade-off in quadruped robots."* Robotics and Autonomous Systems, 2013.

[2] M. Sharbafi, et al, *"Increasing the Robustness of Acrobot walking control using compliant mechanisms."* IROS, 2011.

[3] R. Tedrake, et al, *"Actuating a simple 3D passive dynamic walker."* ICRA, 2013.