Robust Walking using Piecewise Linear Spring

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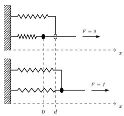
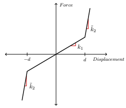
Motivation

Legged system can benefit from compliance for stability, speed, adaptability and robustness. Recently, we have studied the effects of compliant spine in quadruped robots. We have observed that having nonlinearity in the spine compliance can set a better trade-off between speed and energy efficiency. Similar to the spine in quadruped robots, compliance at the hip joint of bipedal robot can also improve the walking performances such as robustness. Here, we test the efficacy of piecewise linear hip compliance for robust bipedal walking.

Piecewise Linear Spring





For nonlinear spring, we focus on piecewise linear spring since:

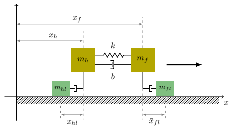
- Minimum parameters to optimize
- Easy to analyze
- Easy to realize

Simple Model for Locomotion

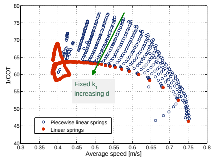
In our previous work, we focused on a simplified model of a bounding quadruped. Our locomotion system consists of two main parts connected to each other by a spring. The spring models the flexible spine while hind and front parts are analogous to hind and front parts of a quadruped.

Most important result

We have observed that having nonlinearity in the spine compliance can set a better trade-off between speed and energy efficiency.



Model of the locomotion system.



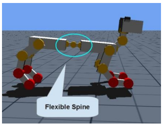
Representation of the linear and piecewise linear spine performances.

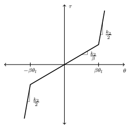
Quadruped with Nonlinear Flexible Spine

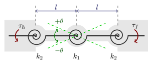
Energy consumption and speed of a quadruped robot with linear and piecewise linear flexible spines are compared using a more realistic model developed in Webot. This quadruped is behaviorally related to the simple model presented earlier; both performing bounding gait.

Three serially arranged rotational springs on the spine result in nonlinear spring (passive spine).

Hip and shoulder joints are controlled on sinusoidal trajectories.







Results

Observed the same trend as in simple model.
COT is improved 55%.

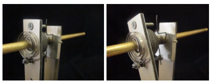
Passive Walker with Nonlinear Flexible Hip

From quadrupedal to bipedal

Similar to the spine in quadruped robots, compliance at the hip joint of bipedal robot can also improve the walking performance.

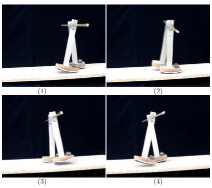
Here, we consider a curved-feet passive walker with hip compliance.

A simple mechanism at hip joint which results in a piecewise linear spring.



Experimental setup

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 piecewise linear spring. Following figure 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.



Performance measure

- Stable: robot walks with a stable and regular gait 1m on the slope
- Damped: slowly stopping after starting to walk
- Stopped: robot suddenly stops after a few stable steps of walking
- Unstable: robot falls down after a few steps of walking

Results

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

As the table shows, 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 (stable) category – as well as its walking distance.

Conclusion

- Compliance can improve locomotion performance.
- Higher degrees of freedom in nonlinear compliance can improve locomotion performance further.
- Piecewise linear spring is a good candidate for nonlinearity since it is easy to realize.
- Nonlinear hip compliance can improve walking robustness.

Future Work

- Study the natural dynamics of nonlinear spring.
- Adaptive methods to exploit such natural dynamics.
- Finding the optimal nonlinear compliance for a specific task.

References

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