Comparing the Effects of Revolute and Prismatic Spinal Joint on Quadrupedal Bounding

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Summary

In the last decade, engineers presuming the importance of flexible torso in quadrupedal locomotion have developed a various set of robots incorporating spine mechanisms. Studies regarding the comparison between different spine designs reach to controversial results due to the complexity of the systems. In this contribution we present preliminary results concerning the comparison between revolute and prismatic spinal joint during passive bounding. Our study is based on two reduced-order dynamic models, featuring a prismatic and a revolute spinal joint. We use numerical return map methodologies in order to calculate passively generated cyclic motions on a wide range of forward velocities. Focusing on high speed bounding, results favor the prismatic spinal joint morphology. In particular, the prismatic spine model features less leg deformation for the same average forward velocity due to the contribution of the spinal spring. Additionally, the extensive bidirectional deformation of the prismatic joint spring leads to lower leg angular velocities during stance in contrast to the revolute spine model.

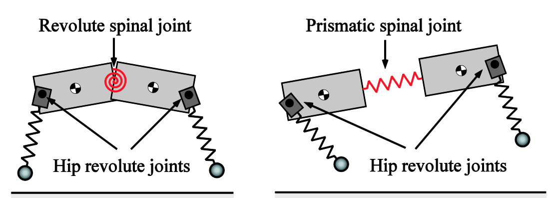
Spine Compliance and Morphology

In nature, quadruped animals owe their performance in part to their flexible torsos. The spine mechanism is fully exploited during high speed running since only then extensive spine oscillations are observed (Maes et al., 2008). Despite the dominating role of spine motion in quadruped running only few works have investigated the effect of spine movements in quadruped robot's locomotion, since spine movement adds a level of complexity to an already complex hybrid system such as a quadruped robot. Recent studies of a reduced-order model of a robot incorporating a compliant revolute spinal joint proved that the dorsoventral oscillations of the flexible torso facilitate leg recirculation during flight phases (Cao and Poulakakis, 2014). Thus, spine compliance contributes to improved energy efficiency (compared to rigid torso robots) but only when the robot realizes highly dynamic motions resulting in high forward velocities. Other studies (Kani and Ahmadabadi, 2013, Pouya et al., 2016) focusing on the compliance and actuation scheme for the spinal joint propose series elastic actuation as the best choice in terms of power consumption.

Although a large number of spine mechanisms has been proposed, spine morphology still remains an open issue. An interesting comparison conducted between different spine design such as a directly actuated revolute spinal joint and a spring-loaded multi-joint spine design (Eckert et al., 2015). The different spine designs were incorporated to Lynx, a small modular robot controlled by a CPG network. The robot with the compliant multi-joint spine design produced reasonably fast and stable bounding gaits but due to the mechanical complexity of the system no further conclusion regarding the preferable design was reached.

Dynamic Models

In this work we compare the effects of a revolute and a prismatic spinal joint on quadrupedal bounding in a template setting. Echoing the significance of spinal compliance and trying to reduce system complexity we employ two simplified passive dynamic models of quadruped robots with different spine designs (Fig. 1).



(a) (b)

Figure 1: Simplified sagittal dynamic models for studying the effect of spine morphology on the bounding running gait. (a) The revolute spinal joint model. (b) The prismatic spinal joint mode.

The revolute spine model depicted in Fig. 1a consists of two identical body segments connected via a revolute spinal joint. The joint is passive and modeled as a torsion spring. Two massless springy legs are connected to the body segments by the hip revolute joints. The model is passive and conservative since no actuation and energy dissipation is considered. The prismatic spine model (Fig. 1b) differs from the aforementioned revolute spine model only in terms of spine morphology. In this case, the spinal joint is prismatic and allows no rotation between the two body segments. The stiffness of the linear spring at the prismatic joint is selected so that the two models have the same natural frequency.

Numerical return map studies have revealed that both simplified dynamic model can perform a large variety of passively realized cyclic bounding motions (Cao and Poulakakis, 2012, Koutsoukis and Papadopoulos, 2015). The bounding motions are characterized by the existence of a gathered and an extended flight phase. That type of bounding motions resemble the high speed running of their natural counterparts and offer an insight to the spine mechanism and its effect on quadrupedal locomotion. Figure 2 depicts the bounding phases of the prismatic spine model, the phases of the revolute are similar.

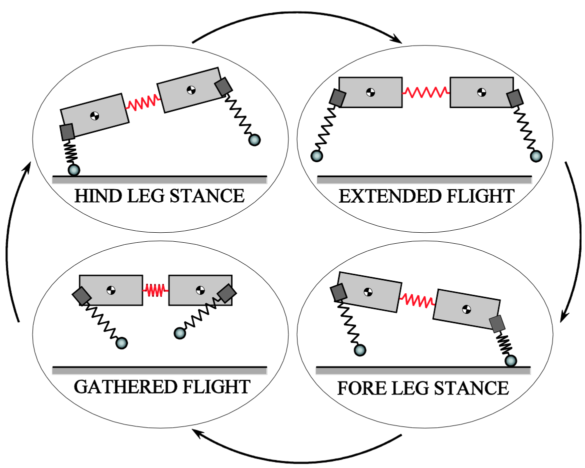


Figure 2: Phases during a bounding stride of the prismatic spine model.

Results and Discussion

In the context of this contribution a large number of passively cyclic bounding motions is calculated for a wide range of forward velocities. The bounding motions of the two models present some interesting features worth mention.

As far as temporal characteristics of the motion are concerned, the stride frequency for both models is closely related to the natural frequency of the model and remains relatively constant for every forward speed. However an interesting difference regarding the stance phases is observed. The prismatic spine model exhibits larger stance phases than the revolute spine model. During these phases the legs of the prismatic spine model exhibit reduced deformation since a large amount of the force needed to propel the body forward comes from the spinal spring. Furthermore, for the same forward velocity, the angular velocity of the legs of the prismatic spine model is relatively smaller from the revolute spine model due to the aforementioned elongated stance phases.

As a closing remark, it is of importance to mention that the prismatic spine model exhibits extensive bidirectional deformation resulting in large forward velocity variations between the two body segments. In contrast, the torsion spring of the revolute spine model exhibits only restricted flexion during the gathered flight phase so the two body segments are moving with relatively the same forward velocity.

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