Passive Dynamic Walking with Quadrupeds - Extensions towards 3D

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SUMMARY

An existing two dimensional model of a passive dynamic quadruped is extended to three dimensions by introducing an additional rolling degree of freedom. This is one in a number of steps towards creating a more realistic model of an actual quadruped and using passive dynamic principles to explain the variety of different gaits found in nature. In this specific example, the preference of actual quadrupeds for lateral foot sequences (which is a consequence of static stability advantages) is examined and it is studied if the static properties have an influence on passive dynamic motions in general.

DETAILS

When extending the principles of passive dynamic walking to quadrupedal locomotion, a simple planar model is able to reproduce two symmetrical gaits: a *two-beat* gait in which the front and back legs swing in phase, and a *four-beat* gait in which the leg pairs are acting 90º out of phase [1]. Because the legs are perfectly rigid, exactly two legs are in ground contact at all times. The duty factor is 50% in both cases.

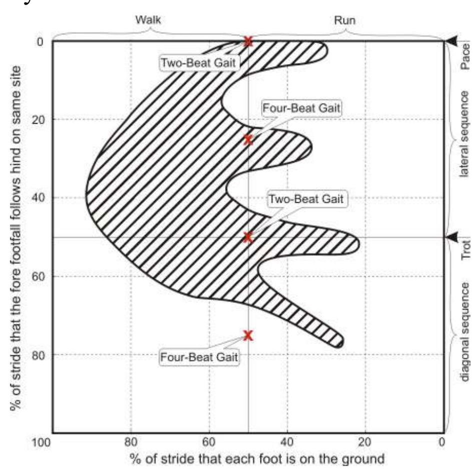

Figure 1: Passive dynamic gaits represent only a few distinct solutions in the continuous range of symmetric gaits found in nature. In 2D, the models are also unable to explain the strong bias towards lateral gait sequences that can be observed in nature. The shaded region was adapted from [2] and shows the distribution "of more than 1000 plots for 156 genera of tetrapods."

Since the simplified model was planar, no difference between left and right existed. This means that a fore footfall is either 0%, 25%, 50%, or 75% behind the hind footfall on the same side, yielding a total four points in the gait graph in Figure 1. The shaded area in the same figure illustrates the considerably larger range of gaits found in actual quadrupeds. Nature utilizes this wide variety to adapt to various conditions, such as different body geometries, weight, or locomotion speeds.

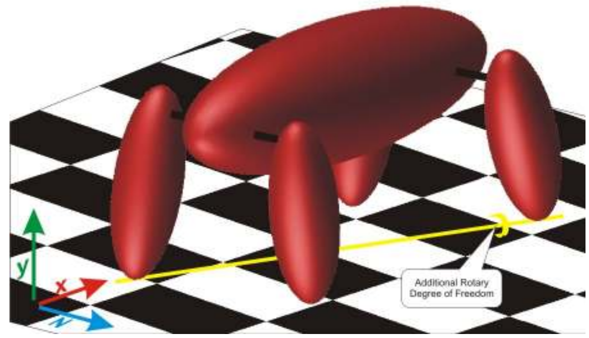

Figure 2: Adding a rolling degree of freedom to extend a passive dynamic quadruped model to 3D allows the study of varying (lateral/diagonal) step sequences.

The passive dynamics and the limited number of gaits produced by them seem to be an explanation for the fourfold indention of this range, but are not able to account for nature's strong bias towards walking gaits in which the legs fall in a lateral sequence. This might not be too surprising, as the effect has been attributed previously to the better static stability of lateral sequences [2], which naturally can only be observed in a three dimensional system.

We try to verify this claim, examine if a beneficial effect of lateral sequences can be reproduced with a passive dynamic model, and assess whether static stability implications are reflected in a dynamic model that (due to the lack of an extended area of support) has no real notion of static stability. This might also improve our understanding of the relation of static and dynamic stability definitions. To this end, an existing model and nonlinear analysis framework are extended to three dimensions. An additional rotational degree of freedom is introduced which allows rolling of the model about the current line of support. The motion within the quadruped (through the hip and shoulder joints) remains planar. Classic Limit Cycle methodology is applied to identify periodic motions and assess their stability as a function of varying parameters such as the hip and shoulder spacing.

REFERENCES

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2. Hildebrand, M. *Integrative and Comparative Biology*. **20**(1): p. 255-267, 1980