Modal Locomotion: Controlling Passive Elastic Dynamics

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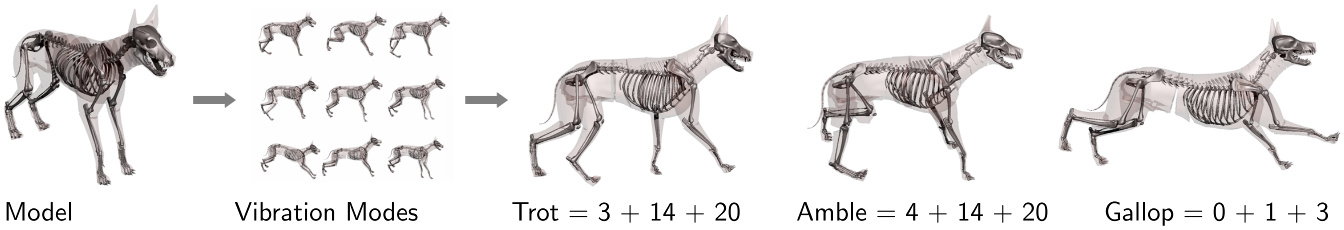

Figure 1: From a dog model in a rest pose and with given tension, the modal vibrations are computed, from which a small collection of movements can be combined to produce compact representations of different gaits.

1 Summary

Locomotion is a fundamental activity of living creatures, but it is also energetically expensive. It is possible that animals have evolved to optimize this energetically expensive function, but they also learn to use their body in efficient ways to produce locomotions that dependent on speed and task [Alexander 1996] (for instance, a slow gate to search for shelter or a fast gate to escape a predator). Learned locomotion strongly depends on the morphology of the animal, and we can deduce a lot of information about plausible modes of locomotion just by observing an animal's musculoskeletal structure. Furthermore, changes such as injury, weight gain, and muscle tone modulation all produce subtle yet important differences in locomotor patterns.

Since humans and animals tend to locomote in an optimal way, it is plausible that we learn how to passively use our own dynamics to minimize the effort of muscular activity. That is, animals can take advantage of swinging limbs and elastic compression at joints in a dynamic cycle that produces locomotion passively, with little or no control at all. This has been demonstrated in robotics with passive mechanical leg systems (i.e., no motors and no control), which are able to generate dynamic walk cycles that closely resemble human walking [McGeer and Alexander 1990].

In real life, the skeletal structure, deformation of tissues, and stiffness of muscles and tendons all play an important role in body dynamics. An appealing strategy for modelling the dynamics of locomotion is to simplify the biomechanical system as a set of rigid bones connected by compliant joints, where the stiffness of joints is due to tendons, the activation of muscles, and the deformation of surrounding tissues. With this simplified model, we then target our study to energetic movements, where the swinging of limbs is predominantly due to elastic forces rather than gravity. In this situation, we can then look at the *passive elastic dynamics* of the system, and focus only on the important, low frequency, global body motions, which can be easily determined by *modal analysis* [Pentland and Williams 1989].

Modal vibrations can be combined in small number to produce locomotion controllers (see Figures 1 and 2). Intuitively, locomotion can be generated with small regular pushes from the muscles to make the whole body vibrate with the selected mode shapes, frequencies, and phases. Searching for controller parameters is greatly reduced since we only need to consider a small number of modes rather than a large number of degrees of freedom. This search can be done by optimization, guided by captured motion analysis, but is also easy enough to do by hand. In fact, the mode shapes make a good low dimensional basis for interactive human control with a mouse or haptic device (see Figure 3).

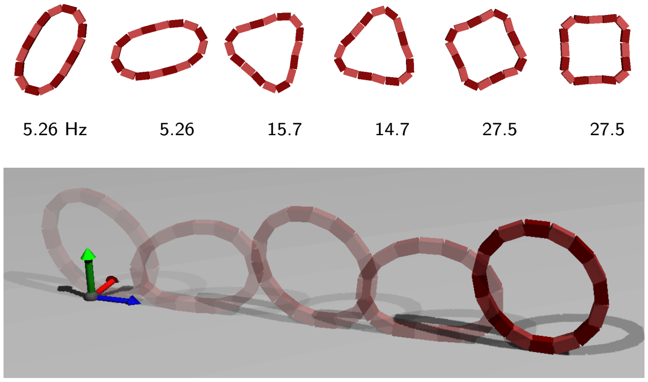

Figure 2: Simple articulated model with rigid blocks and compliant joints. Top shows vibration modes, and bottom shows locomotion control obtained using a combination of only the first two modes.

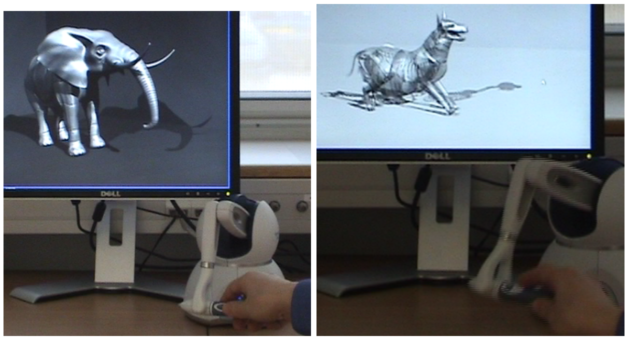

Figure 3: Interactive manipulation using mode shapes.

References

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