Introduction

Some apes are able to swing through the trees with motions that are at once awe inspiring and also remarkably smooth. Are there any simple mechanical concepts that help explain this kind of locomotion? Here we pursue the idea of minimization of effort in the extreme. In particular, we seek models of brachiation that have zero energetic cost. In detail, this means we have crudely modeled apes as simple rigid body linkages and sought periodic motions that are reminiscent of biological brachiating and that conserve mechanical energy. Most simply, this boils down to the search for motions with no impacts.

Long armed apes have two distinct brachiating “gaits”; 1) a continuous contact gait where one hand is always in contact with the overhead support and 2) a faster ricochetal gait with a period of free flight between handholds. Both of these motions are incredibly smooth and pendular in aspect. Further, the hands don’t make jarring impacts when grabbing a new support. Given these observations and the obvious imperative for energy efficiency, we conjectured that we could find periodic passive- dynamic motions that are perfectly efficient. To test this hypothesis we examined a series of two dimensional, rigid body, passive models for periodic, energy conserving motions.

Methods

Brachiation has been studied by both direct observation [Fleagle, 1974] and by the creation of simplified models [Bertram et al., 1999].

Numerical simulation of the nonlinear equations of motion, for some simplified models, was the main tool of our investigation. We first derived the equations of motion for the rigid body system to obtain the set of ordinary differential equations which govern the motion of the system. This simulation was then treated as a function where, for a given input (the initial conditions of the system) an output was returned (the state of the system when one of the periodicity requirements was met). This allowed us to use root finding and continuation methods in order to find periodic motions.

Results and Discussion

Point Mass Model

A simple brachiation model is a point mass with a massless arm which can be placed anywhere in
order to grab the handhold at any time [Bertram et al., 1999].

Continuous contact solutions require that the mass reach zero velocity at the instant when the supporting handhold is switched. The ricochetal gait requires that the velocity of the point mass, in flight at the instant when the handhold is grasped, be tangent to the circular swing trajectory about the new handhold; i.e., the ricochetal gait requires matching the slope between a circle and a parabola. Whole families of solutions exist for a given set of the model’s parameters in both continuous contact and ricochetal gaits. Fig.(1) shows a typical ricochetal gait.

**Single Rigid Body Model**

The first natural extension of the point mass model is a single rigid body with inertia. This model has one more degree of freedom thereby allowing more intricate behavior. The existence of the trajectory shown in Fig.(2) can be tentatively predicted by a counting argument. The system has two degrees of freedom when the hand is grasping a handhold. If the cycle goes from the beginning of the handhold grasp to the beginning of the next handhold grasp we have four initial conditions, \((\theta_1, \theta_2, \dot{\theta}_1, \dot{\theta}_2)\) and four periodicity requirements; positions and velocities of each “link” must be the same at the end of the cycle as they were at the beginning.

**Three Link Rigid Body Model**

The three link model resembles a brachiator with two arms and a body. The requirement on the motion for no collision to occur is that the velocity of the “swing hand” must be zero when it makes contact with the ceiling to grasp the next handhold. Many collisionless gaits are possible for each set of parameters. As can be seen in Figs.(3-4) the arms swing passively from handhold to handhold making smooth contact at the grab. Meanwhile the body swings underneath in a manner reminiscent of actual gibbon brachiation.

Comparisons between the computer simulations shown in Fig.(4) and video clips of gibbon brachiation shown in Fig.(3) show some similarities.
The motions we found show that perfectly energy efficient brachiation is possible with a rigid body model. Since the motions depicted in Figs.(3-4) are similar, it is indicative that brachiators might be relatively close to passive-mechanics collision-free motions.

References


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