The search for universal parameters for describing bipedal gaits

Simon D. Wilshin and Monica Daley
Royal Veterinary College, University of London
Contact: *swilshin@rvc.ac.uk*

1 Introduction

Birds walk, hop, run and sometimes skip. At higher speeds birds will run with an aerial phase, at lower speeds they will run grounded with double support. Although considerable progress has been made (for example[2]), it is still unclear precisely what factors determine gait usage. Can gait selection be said to be determined by energetic economy, stability, or some other factor?

To determine what factors govern gait selection we must first understand what aspects of dynamics consistently differentiate gaits. Walking, hopping, running skipping and so forth, all of these different locomotor patterns have been described as gaits, but in many cases it remains unclear in what precise sense these gaits are distinct.

2 State of the art

To an extent the problem of finding what factors determine gait is constrained by our ability to define precisely what a gait is and how they should be distinguished. Gaits have been described as a pattern of locomotion, a view refined by Alexander[1]:

“A gait is a pattern of locomotion characteristic of a limited range of speeds described by quantities of which one or more change discontinuously at transitions to other gaits.”

An example of distinct gaits under this view would be quadrupedal trotting and galloping in domestic dogs. In trotting, the relative limb phase of diagonal pairs of limbs is approximately zero, in galloping the limbs move out of phase. In the transition the switch between these extremes is approximately discontinuous.

However, for some birds[3], it is sometimes unclear if walking and running are indeed distinct gaits under this definition as characteristics change continuously with speed. Further, is has been observed[6] that no abrupt transitions in mechanical parameters occurs between grounded and aerial running in ostriches, suggesting that under Alexander’s definition these are the same gait. As a result one is left with the unsatisfactory and counter intuitive conclusion that birds only exhibit a very small number of gaits.

This is unsatisfactory because it would seem reasonable to assume that the factors (energetics, stability, etc.) governing both gait usage and the form of the transition between gaits may vary in importance as conditions change. A classification scheme which does not differentiate at least some of these locomotor patterns, while potentially useful in other contexts, will not permit hypotheses to be formulated which are contingent on distinctions between what we would otherwise identify as distinct gaits.

Another perspective can be obtained by defining a gait as a locomotor pattern which is well described by some system of dynamical equations. For example, running gaits such as hopping and bipedal running are well described by the Spring Loaded Inverted Pendulum (SLIP) and walking gaits can be described by a stiff inverted pendulum.

This scheme would seem to offer a solution to our problem, since these models offer a clear distinction between walking and running, the relative phase of the kinetic and potential energy modes is different in each model. This phase relation is the current widely accepted definition of the distinction between walking and running.

In addition, the limb stiffness implied by these models is different for walking and running. However, it has been shown[5] in a readily realisable model that the same parameterisation (including limb stiffness) can lead to either gaits we would identify as walking or running dependent only on initial conditions. Different kinetics described by the same dynamics.

This problem is compounded by the observation that both walking and running gaits can be described by a double spring mass system[4]. When the spring constants of such a system is high, that is, when the system is stiff, it can be made to perform a walking gait. When the spring constants of such a system are comparatively low it can be made to perform a running gait.

Before we can begin to ask what factors determine gait use in birds, we will need a clear understanding of how best to distinguish walking and running. We must reconcile the following facts:

- Walking and running in birds are in some sense indistinguishable (either because there is no abrupt change in mechanical quantities, or because they can be described by the same system of dynamical equations).
- Walking and running are distinguished in part by initial conditions (as in[5])

- Walking and running are distinguished in part by limb stiffness (as in[4])
- Walking and running are distinguished in part by the relative phase of kinetic and potential energy modes.

It is our intention to explore the nature of bipedal gaits experimentally in birds. We do this with a two fold purpose. Firstly we would like to construct a classification scheme for gaits which provides a precise description at the walk-run transition, regardless of if that transition is abrupt or otherwise and which allows for the possibility that these gaits can be distinguished by initial conditions, limb stiffness, relative energetic phase, or some combination of these and other factors. Secondly to determine what factors lead to the structure of this transition, how those factors vary with condition, and how that in turn impacts gait selection.

3 Proposal

The separation in phase which occurs for some bipedal systems between walking and running gaits occurs in another situation relating to bipedal locomotion, specifically when considering hopping and running. In this case it is the relative limb phase which takes on discrete values.

We will treat this case as a toy model from which to draw inspiration for a classification scheme by considering symmetries of the equations describing walking and running (and the related state spaces). That the relative limb phase is quantised is reflected in (or a result of) the symmetry of the equations describing hopping and bipedal running. Interchanging left and right limbs in these equations is a symmetry and this implies that relative limb phase will take discrete values.

In guineafowl the relative phase of the kinetic and potential energy modes are observed to be close to out of phase at low speeds, and close to in phase at higher speeds (Figure 3).

It is our intention to take the equations which describe both walking and running (either those of O'Connor[5] or those of Geyer *et. al.*[4]), determine if a comparable symmetry exists in these equations, and find under what conditions this symmetry holds. We will also determine what factors (energetics, stability, etc.) play a role in imposing this symmetry should it exist.

4 Open Questions

Is there a similar symmetry to of left / right limb interchange hidden in the equations describing running and walking gaits in bipeds? If this symmetry imposes the requirement that kinetic and potential energy modes oscillate with fixed phase relations, do we expect the symmetry will break down near the transition. What factors can cause this break down?

Can we use this symmetry to construct an empirically grounded scheme for distinguishing walking and running

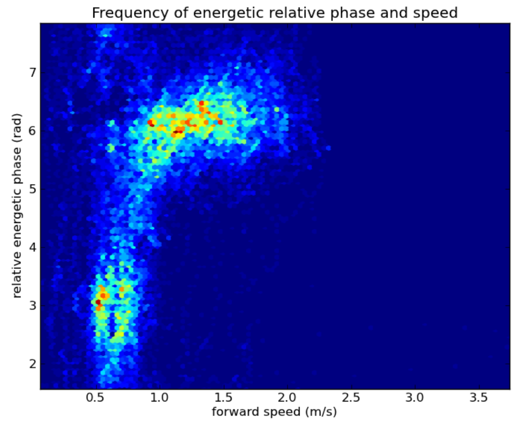

Figure 1: Frequency plot (hotter colours corresponds to more frequent) of relative energetic phase against speed showing two distinct regions, walk at low speed and running at higher speed

gaits? If such a symmetry is present what factors (energetic cost, stability) cause its imposition.

Format Poster

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