WHY DON'T HEXAPODS GALLOP?

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ABSTRACT

The main contribution of this paper is to explain why the overwhelming majority of hexapods don't employ the rectilinear gallop using simple mechanical arguments.

1 Three constraints on galloping quadrupeds:

1. For all quadrupeds the rectilinear gallop necessarily employs one phase where its limbs are in contact with the ground and a second flight phase where its limbs are not in contact with the ground.

2. Given that the rectilinear gallop requires that the organism travel in approximately a straight line in a single direction there is a necessary division of mechanical labour. The forelimbs are specialised for traction whereas the hind limbs are specialised for propulsion.

3. The division of mechanical labour implies that the forelimbs are in phase with each other and out of phase with the hind limbs.

Given that four limbs are necessary for galloping and many quadrupedal mammals can gallop, four limbs are also sufficient.

2 Energetic costs on galloping hexapods:

In order to demonstrate that hexapods have no advantage over galloping quadrupeds we shall compare a hexapod H and a quadruped Q of equal mass and analyse the energetic difference.

1. In order for this hexapod to gallop as fast as a similarly-sized quadruped it must have similar limb lengths since, according to the dynamic similarity hypothesis [2], rectilinear acceleration is approximated by:

$$a \approx \frac{v^2}{L} \tag{1}$$

2. Given the equal mass assumption, each limb will experience similar normal forces. Now, given that tensile strength is proportional to cross-sectional area, a cylindrical limb approximation yields:

$$M \cdot \frac{v^2}{L} \propto R_H \implies \langle R_H \rangle \approx \langle R_Q \rangle \tag{2}$$

where $\langle R_H \rangle$ denotes the average limb radius of the hexapod.

3. If we assume that the hexapod and quadruped have identical cylindrical limbs we may note that the rotational kinetic energy consumed by the hexapod, E_{rot}^H is approximately:

$$E_{rot}^H \approx 1.5 \cdot E_{rot}^Q \tag{3}$$

since each limb must be actuated independently of the others.

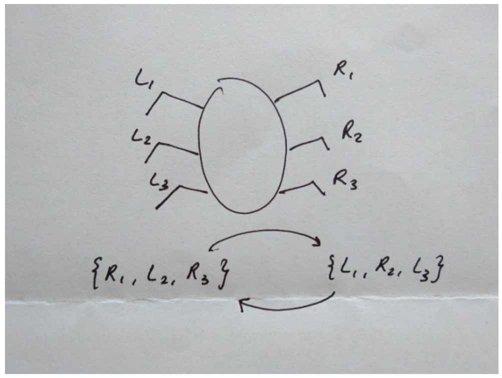

Figure 1: alternating tripod gait of a hexapod

3 Strengths and Limitations of Hexapod locomotion

1. **Limitations:**

Although reductive, our comparison of the energetic profiles of hexapods vs. quadrupeds indicates that in the presence of macroscopic forces a hexapod is unlikely to outrun a quadruped. In other words, a cheetah born with six limbs rather than four is unlikely to succeed in passing down its genes. That said, in 2013 three galloping beetles were discovered [3].

The authors of [3] note that although *P. endroedyi*, *P. hippocrates* and *P. glentoni* can walk using the normal tripod gait these beetles usually employ a unique galloping gait where they move each pair synchronously, stepping alternating with the front and middle legs. The hind legs are dragged behind even if the beetle carries no load and seem to contribute little to propulsion.

2. **Strengths:**

The advantage of hexapods over quadrupeds emerges when instead of emphasising speed/acceleration we focus on static stability. Six limbs is the smallest number of limbs that allows an organism to utilise an alternating tripod gait, which allows its centre of gravity to always lie within the area of support. It follows that the hexapod, unlike the quadruped, has the advantage of static stability at every instant of locomotion and therefore consumes less energy at low speeds.

4 Discussion

The arguments provided here are rather qualitative in nature and far from exhaustive. On the one hand, a challenge facing more detailed analyses of hexapod locomotion is that the overall generality of the analysis tends to disappear. On the other hand, any approach using a general mathematical model would necessarily be underdetermined since any given hexapod potentially has an infinite number of biomechanical parameters.

Considering that a definitive solution is out of reach, we may consider approaches that lead to much greater insight. One approach would be to simulate biological evolution as a stochastic optimisation problem starting from a population of hexapods with a finite number of variable biomechanical parameters. The aim would be to minimise an energetic cost function that corresponds to travelling in a straight line on a given surface at a particular velocity.

References

[1] C. Vaughan & M. Malley. Froude and the contribution of naval architecture to our understanding of bipedal locomotion. 2004.

[2] Alexander RM, Jayes AS. A dynamic similarity hypothesis for the gaits of quadrupedal mammals. 1983.

[3] Smolka et al. A new galloping gait in an insect. 2013.