Towards a Synthetic Science of Legged Locomotion: Component Comparisons in Animals and Robots

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Recent progress in mobile robotics has resulted in legged machines that begin to approach animals in their agility, endurance, and robustness. These robots differ in significant ways from living runners. For example, robots use discrete components formed and assembled at the macro scale, whereas animals use distributed, hierarchical structures grown from the nano-scale. The technologies we use for power, actuation, and signal transmission are based on fundamentally different physical processes. On the other hand, legged robots bear some striking similarities to their natural counterparts in their overall structure and function. Legged robots typically share similar overall morphologies (2, 4, or 6 legs attached to a body). They both require the same sets of "components" – subsystems that accomplish functions critical to locomotion. Components include, but are not limited to a power system to store and deliver energy to the runner; actuators to deliver and modulate mechanical energy; sensors to perceive self and environment; structural materials to form a skeleton for support and leverage; and a control system to direct actuation. As an engineering-inspired first step towards a synthetic science of natural and engineered locomotion, we develop metrics that characterize the performance of these components so they can be compared directly in the context of legged running. In doing so, we quantitatively reveal some extreme differences—for example, signal transmission speeds that differ by six orders of magnitude—and some remarkable similarities—for example, bone and steel can make a femur of similar failure resistance and weight.

The potential benefits of comparisons to roboticists are straightforward: pinpointing the deficits of available components or of their integration could highlight areas ripe for progress. But we argue that our robotics-inspired approach can provide unique insight into biological design as well. Just as nature affords us the only opportunity to observe a technology other than our own [1], legged machines offer a window into an alternate world where animals are made from a whole new set of components. By examining the impacts of distinct physical mechanisms on subsystem performance, we may reveal the constraints imposed on animal morphology by the particular physics of biological components. Robots can advance our understanding of basic biomechanics by acting as physical models [2], but differences in the component-level physics can undermine comparisons or lead to inappropriate conclusions by false analogy. Yet, developing a truly comparative science of locomotion across the animal-machine divide could advance robotics and biology together.

References

[1] Vogel, Steven. *Cats' paws and catapults: Mechanical worlds of nature and people*. WW Norton & Company, 2000.

[2] Koehl, M. A. R. "Physical modelling in biomechanics." *Philosophical Transactions of the Royal Society of London B: Biological Sciences* 358.1437 (2003): 1589-1596.