Bend and Flex: Passive Flexibility or Active Control in a Quadruped Animat

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ABSTRACT

Muscle and tendon elasticity enables animals to interact with their environment *softly*, reducing ground impact force and increasing efficiency of locomotion. Traditional rigid body robots remain the commercially viable option, but incorporating flexibility can harness the benefits exhibited by natural organisms. In this paper, we examine how the addition of passive flexibility impacts performance and locomotive efficiency in a quadruped animat. Results show that the addition of flexibility in the spine and lower limbs of a quadruped animat significantly increases the distance traveled compared to a fully rigid-body animat. However, replacing these passively flexibile joints with actively controlled joints results in the farthest traveling individuals while maintaining similar efficiency. It appears that increases in DOF and joint configuration are the drivers of performance increases rather than passive flexibility.

CCS CONCEPTS

• **Computing methodologies → Artificial life**; **Genetic algorithms**;
• **Computer systems organization → Evolutionary robotics**;

KEYWORDS

Evolutionary robotics, animats, morphology, passive flexibility

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1 INTRODUCTION

Animals exhibit a remarkable ability to adapt locomotion to varying conditions. Gaits are driven by responses from the central nervous system and the morphology of the organism itself. Often, characteristics of the musculoskeletal system, such as elasticity of the tendons, contribute to their movements. Whereas, robotic systems typically comprise rigid-body components, connected with single degree-of-freedom (DOF) actuators, such as servo motors and linear actuators. Rigid components lack the flexibility of their biological analogues, but compliance can be added to a robot with springs, reducing the energy required for locomotion [1].

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In previous work [4], we found that a flexible spine increased locomotive performance in a quadruped animat. However, it remains an open question as to whether the performance gains were due to flexibility or simply the increase in the number of DOF in the animat. If the same joints were placed under active control, would locomotive performance still improve? Would active control exceed passively flexibile joints in terms of performance or efficiency?

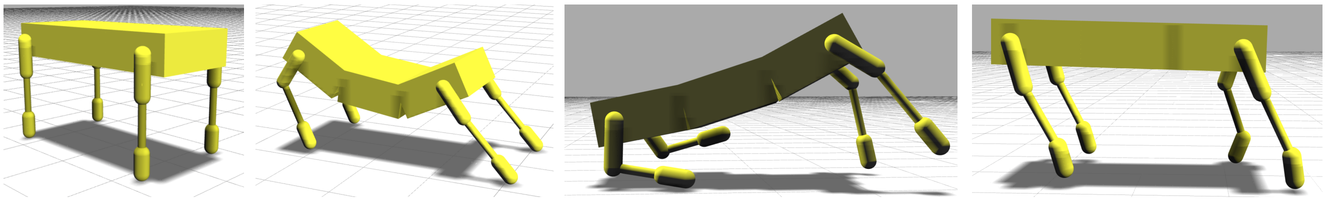
In this study, we investigate how augmenting a rigid-body quadrupedal animat with passive flexibility or actively controlled joints changes performance. Figure 1 shows the different components added to the animat. Seven treatments augment the animat beginning with a base quadruped animat with no passive flexibility. We next add sliding joints to the lower limbs and a flexible hinge joints on the spine. Finally, we replace the passive joints with actively controlled joints. We also address whether performance increases might simply be due to additional DOF in the animats.

Our results indicate that passive flexibility significantly increases distance traveled over the base quadruped. However, replacing flexible joints with actively controlled hinge joints produces the furthest distances traveled. Efficiency does not significantly change between passively flexible and actively controlled joints. We find that flexibility increases the performance of a robotic system, but the performance increase is more likely driven by increasing DOF in the animat.

2 METHODS

Animats are evaluated in the Open Dynamics Engine (ODE) [6], a 3D rigid-body physics simulation engine. ODE models passive flexibility by connecting rigid-bodies with spring-like joints. The base quadruped animat is shown in Figure 1a. The torso is composed of three segments connected by fixed joints. Each leg is three segments with hinge joints at the hip and knee. In the base configuration, the joint connecting the lowest component to the mid-leg is fixed, effectively creating a short upper segment and a longer lower leg segment.

Other animats are derived from the base configuration by adding a passive or active spine combined with a passive leg slider or active leg hinge. Figure 1b shows a quadruped animat with a flexible spine. Here, the rigid joints in the torso are replaced with passively flexible hinge joints that actuate along the lateral planes of the animat. Figure 1c shows the addition of flexible slider joints between the two lower limb segments. They compress during locomotion acting as shock absorbers. In the figure, the slider on the right rear leg is at maximum compression. Figure 1d shows a quadruped animat with actively controlled hinge joints on the lowest joint of each leg. An animat with an actively controlled spine is not shown, but is similar to the animat pictured in Figure 1b.



(a) (b) (c) (d)

Figure 1: The quadruped animat is augmented with passive flexibility and actively controlled joints. Seven configurations are examined. Four are pictured here. (a) Base (no joints) quadruped animat. (b) Flexible spine added. (An active spine is similar, but the joints are under active control.) (c) Flexible sliders added to the lower limbs. Note the compressed slider in the right rear leg compared to the extended slider in the front right leg. (d) Sliders replaced with actively controlled hinge joints on the lowest joint in each limb.

Populations comprise 120 individuals evolved over 4,000 generations using the DEAP framework [3] with a conventional generational genetic algorithm. Fitness is the Euclidean distance from the starting point to the center of the torso after 10 seconds. Genomes consist of parameters for the sinusoidal oscillating control signal, joint forces, and additional parameters defining flexibility.

3 RESULTS AND DISCUSSION

The primary goal of our study is to assess the contributions of passive flexibility to a quadruped animat, and determine whether actively controlled joints produced similar, or increased, fitness levels. Figure 2 shows the distance traveled in body lengths of the best individual per replicate across treatments. Adding a flexible spine (FSpNS - Flexible spine no sliders) does not significantly improve performance over the base animat. Whereas, passively flexible sliders (FS - flexible sliders and FSpFS) have significantly higher performance. The most effective individuals in the study have actively controlled hinges (treatments denoted with HL for hinge on lower legs) on the lower limbs (HL, HLFSp, HLASp - hinge lower active spine).

Adding flexibility to the animat significantly increases distance traveled versus the base animat. This supports observations in earlier works [2, 5] that have incorporated flexibility in robotic systems. Here, movement in the lower limbs through passive sliders improves locomotion moreso than flexibility in the spine. However, actively controlled joints evolve the highest performing individuals and similar efficiency.

A second potential explanation for locomotive improvements is the DOF in each configuration. Within the passively flexible treatments (FSpNS, FS, FSpFS) the DOF are 10, 12, and 14 respectively. A similar increase in the actively controlled treatments occurs (HL - 12, HLFSp - 14, HLASp - 14). As shown in Figure 2, distance traveled generally improves within the two treatment groups as DOF increase. Across all treatments, increases in DOF appear to drive performance increases, rather than specific features like passive flexibility. Increasing DOF allow more dynamic movements to evolve, facilitating locomotion.

Although not the highest performers, incorporating flexibility could still be beneficial in robotic systems depending on the problem constraints. Active control could require additional hardware in the form of servo motors, increased battery capacity, and wiring constraints. A designer might want to avoid the increases in complexity. Instead, a controller can harness passive joints improving performance as demonstrated here.

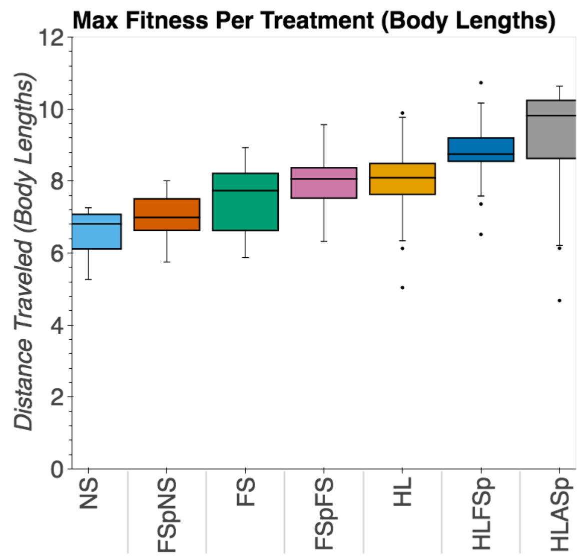


Figure 2: Distance traveled of the best individual per replicate across treatments. 20 replicates per treatment are conducted.

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