The viscoelastic properties of the legs can enable a wide range of gait initiation dynamics when coupled to a CPG in a simulated quadruped insect

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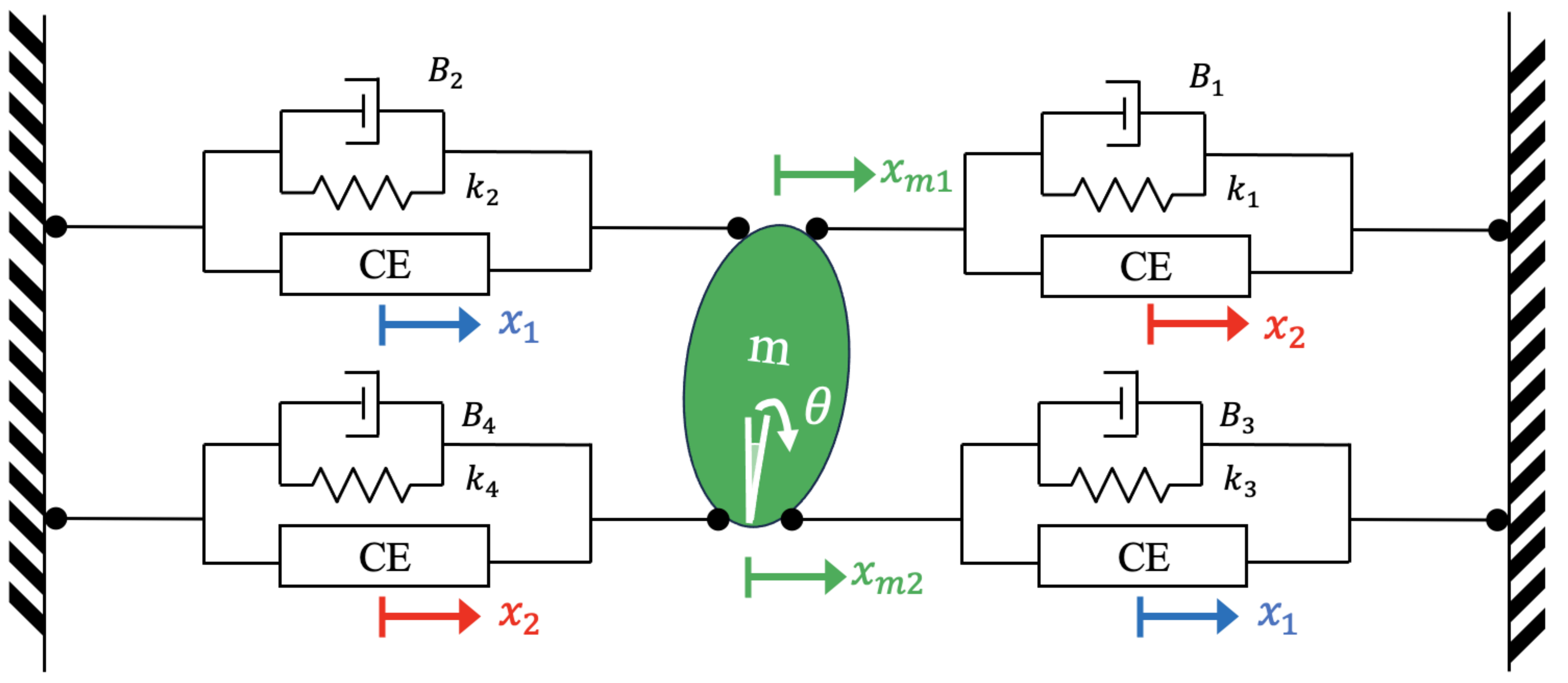
Introduction

Understanding how locomotion is initiated and transitions enables progress in bio-inspired robotics. The relevance of mechanical system dynamics is often excluded from discussions of fictive locomotion under control of a Central Pattern Generator (CPG). Coupling a mechanical system model with a CPG can reveal the brain-body co-evolution and co-adaptation for multi-legged locomotion [1-2].

Goal: Investigating the influence of viscoelastic parameters on locomotion patterns and stability of a simulated quadruped insect controlled by a Matsuoka CPG.

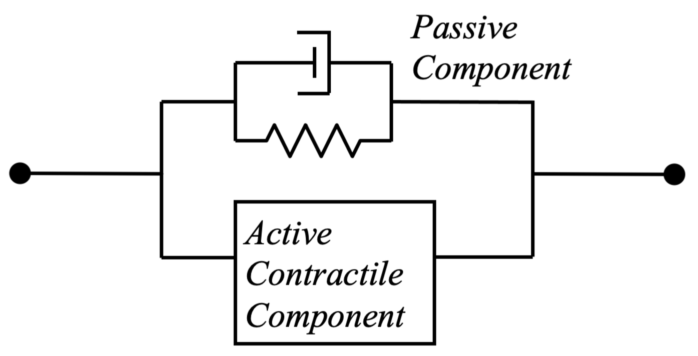
Methods - Viscoelastic Model

To simulate a quadruped insect, a 2DOF (translational and rotational) viscoelastic mechanical model was constructed for a 0.1kg ovoid body suspended between two walls. Opposite legs were driven in pairs following quadruped walking gait patterns [3].



Mechanical free-body diagram of the abstract insect with translational and rotational motion.

Leg muscles were simulated using the Hill-Type muscle model, with the muscle abstracted to a spring element (k), a damping element (c), and a linear actuator driving contractions (x_n).



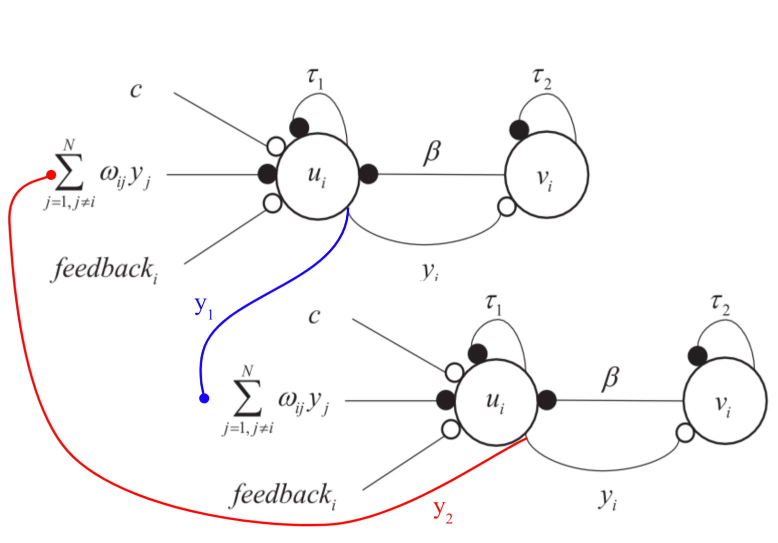
Hill-Type muscle model

$$m\ddot{x}_m = -c_1(\dot{x}_{m1}+\dot{x}_2-\dot{x}_1)-c_2(\dot{x}_{m1}-\dot{x}_1)-c_3(\dot{x}_{m2}+\dot{x}_1-\dot{x}_2) - c_4(\dot{x}_{m2}-\dot{x}_2) - k_1(x_{m1}+x_2-x_1) - k_2(x_{m1}-x_1) - k_3(x_{m2}+x_1-x_2) - k_4(x_{m2}-x_2) \quad (1)$$

$$I\ddot{\theta} = \tau_{x1} - \tau_{x2} \quad (2)$$

Equations of Motion

Matsuoka Dual-Neuron CPG



A dual-neuron Matsuoka CPG was chosen for fictive locomotion generation. The model produces neuron outputs that create rhythmic motion following walking locomotion where one neuron activates its associated viscoelastic arm, while the other neuron remains inactive. Output information (y_1,y_2) is passed between the neurons as feedback and used to drive the legs.

$$\tau_1 \dot{u}_i = c - u_i - \beta v_i - \sum_{j=1, j\neq i}^{N} \omega_{ij} y_j + \text{feedback}_i \quad (5)$$

$$\tau_2 \dot{v}_i = y_i - v_i \quad (6)$$

$$y_i = \max(0, u_i) \quad (7)$$

Parameter	Value
N	2
s	5.0
q	1
Tr	1/32
Ta	1/2
b	2.0
ω	2.0

Results

Viscoelastic properties (c,k) were varied between $0 \le k \le 30$ and $0 \le c \le 1$, and Monte Carlo simulations were conducted for transient (10 steps [4]) and steady-state (20+ sec) locomotion. Phase portraits for translational and rotational motion were analyzed and classified using zero-crossings.

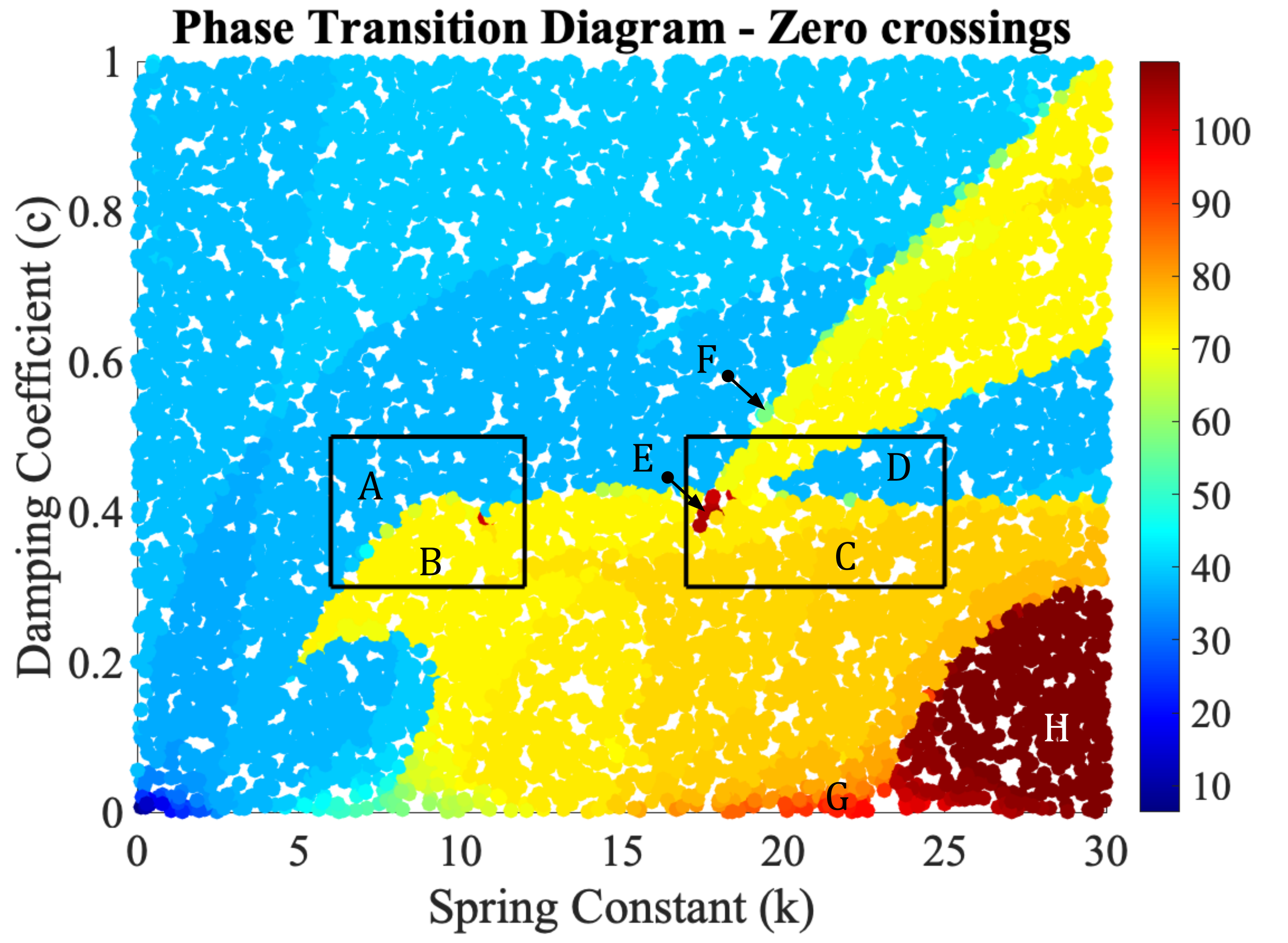
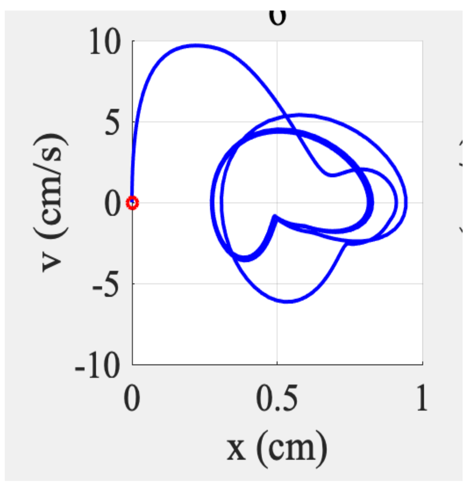


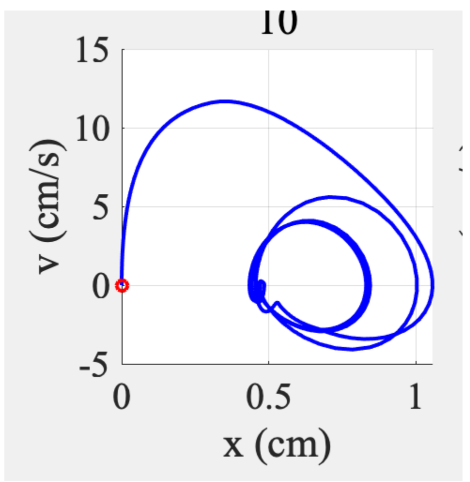
Fig 4. Phase transition diagram of translational movement 1 with points of interest for t=10s. Regions of interest of $0.3 \le c \le 0.5$ Ns/m and $6 \le k \le 12$ and $17 \le k \le 25$ N/m were chosen from measured values from cockroach models [3].

The viscoelastic combinations classify into 8 distinct movement patterns experiencing single-well (B), distorted single-well (A), and two-well attractor (E) phases.

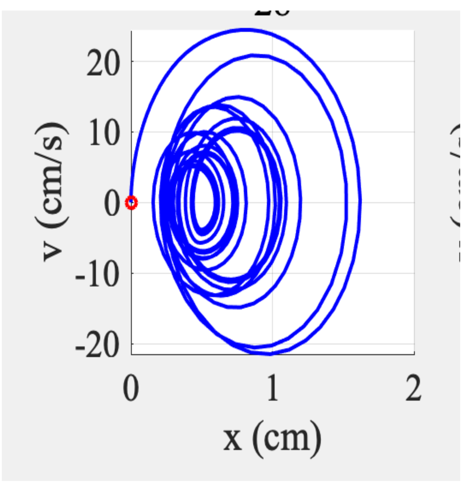
A.



B.



E.



Discussion

Tuning leg viscoelasticity can enhance biorobotic versatility. Viscoelastic parameters with low damping (c < 0.2 Ns/m) and high spring constants (k > 25 N/m) exhibit sophisticated behavior, characterized by the presence of two-well attractors (Duffing's), that reveal the potential need for robust controllers that may nevertheless be a built-in enabler of legged agility.

Gait initiation dynamics is determined by brain-body coupling. Viscoelastic parameters alter translational movement phase and transient movement behavior.

Coupling viscoelastic legs to CPGs highlights brain-body co-adaptation for versatile movement. Coupled neuro-mechanical systems, tunable via muscle activation and mechanical properties [5], impose limitations and opportunities for the mechanics of legged locomotion [6], at times even being loosely coupled to the Matsuoka CPG's forcing function. This work expands the possibilities for locomotor patterns for the initiation of gait vs. steady state locomotion—as well as gait transitions—for bio-inspired robots on the basis of the viscoelastic properties of the legs [7].

References

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