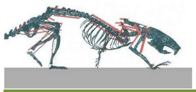


Agile and Adaptive Robotics Laboratory

Building a Biomechanical Model of the Rat Forelimb

Joshua N. E. Mak[1], Fletcher Young[2], Cody Scharzenberger[1], Matthew Tresch[3], Roger Quinn[2], Alexander J. Hunt[1]

[1]Deptartment of Mechanical & Materials Engineering, Portland State University, Portland, OR, [2]Deptartment of Mechanical and Aerospace Engineering, Case Western Reserve University, Cleveland, OH, [3]Department of Physiology, Northwestern University, Chicago, IL.

Abstract

We are developing a biomechanical model of the rat to test theories of neural control in balance, standing, walking, and running. Several biomechanical models of rat hindlimbs have been developed and have explored the effects of multi-muscle control during locomotion . Here we show a biomechanical model of the rat forelimb. The forelimb model uses two ball-and-socket joints to model clavicle and scapula movement. A third ball-and-socket joint is used at the shoulder and two hinge joints are used at the elbow and wrist. Scapula motion is further constrained by muscle and spring elements. Each forelimb has 11 degrees of freedom, and 23 Hill-type muscles. The model has been created in Animatlab, which includes both a neural design component and a physics environment. Muscle paths are hand guided to approximate the origin and insertion points necessary to replicate multi-body articulation. Most muscles are represented with a single linear muscle path, except in cases where muscle wrapping was necessary around joints or bones. In this work we explore multiple methods for setting passive muscle parameters, including the use of scaling heuristics and optimization with experimental data. Stiffness and damping muscle parameters are being validated against kinematic and kinetic data from the rat. The muscles in this model will then be activated using a synthetic nervous system to test theories of balance and locomotion control.

Introduction

Animals can effortlessly achieve complex locomotion as well as superb balance control, however similar accomplishments still prove elusive for modern robots. Understanding how balance is controlled is still a process not very well understood. Extensive models have been developed to represent the hindlimb, however few attempts have been made to develop a forelimb model.

Mechanical Model

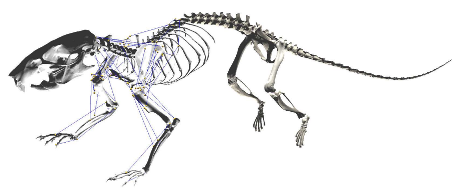
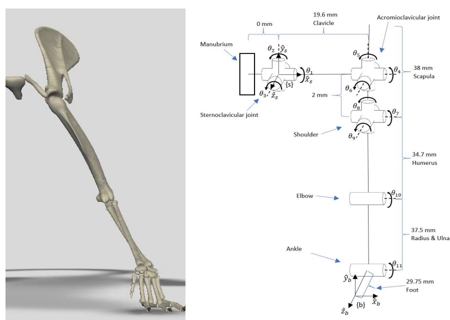


Figure 1. The simulated rat forelimb model using Animatlab software. Graphics objects and muscles (blue lines) are shown, collision objects not shown.



(a) (b)

Figure 2. a) Demonstrates the skeletal structure of the forelimb. b) Illustrates the mathematical model of the rat forelimb. The ball and socket joints at the sternoclavicular joint and acromioclavicular joint allow the large articulation seen in scapula movement.

Individual Muscle Properties

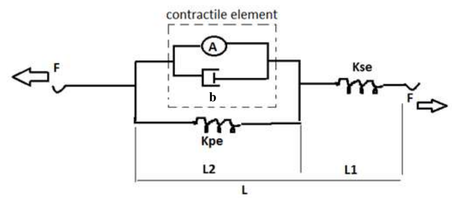


Figure 3. The Hill-muscle model representing the muscle spring and damping element as well as the tendon spring element.

The governing equation used is:

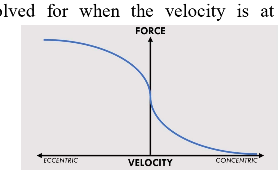
$$\dot{T} = \frac{k_{se}}{b}\left(k_{pe}L + b\dot{L} - \left(1 + \frac{k_{pe}}{k_{se}}\right)T + A\right)$$

The model requires passive muscle parameters such as the muscle spring (k_{pe}) and damping coefficient (b) as well as tendon/ligament spring coefficient (k_{se}). One possible method for determining these parameters involves using published Young's modulus (E) for skeletal muscle.

$$k = \frac{EA}{L}$$

Here the cross-sectional area (A) being used is the physiological cross-sectional area (PCSA) to account for the pinnation angle of the muscle fibers. The damping coefficient can be determined using force-velocity relationships and solved for when the velocity is at maximum.

$$b = \frac{-k_{pe}L - A}{\dot{L}}$$



Next Steps

Determine Passive Muscle Properties

Passive muscle properties will be determined using relationships from pre-existing hindlimb data

Stimulate Muscles

The simulated muscles will be stimulated by a synthetic nervous system in the Animatlab software.

Test Model

The model will be tested and compared to real rat kinematic and kinetic data.

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