Bayesian Estimates of Plausible Muscle Forces in Musculoskeletal Simulations

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Introduction

- Biomechanists are interested in estimating muscle forces underlying observed behaviors, but accurately determining muscle forces is difficult:
  - Uncertainty in choosing modeling parameters [1]
  - Experimental data prone to measurement error
  - Sensitive to the objective function [2]

- Measuring muscle forces *in vivo* is prohibitively invasive

- Bayesian inference methods can allow us to take into account priors on uncertainty inherent in estimating muscle forces

Aim: To evaluate the feasibility of using Markov Chain Monte Carlo (MCMC) analysis [3] to
(1) recover parameters in a simple mechanical model
(2) estimate range of plausible muscle forces (excitations) in simple elbow flexion task

Methods

- To test the MCMC algorithm, we simulated a mass-spring-damper system (Fig. 1) using seven arbitrarily chosen parameters to generate a reference motion
- We used the reference motion as input to the MCMC algorithm, the goal being to find the seven parameters

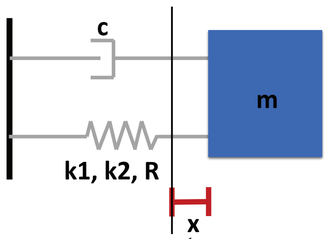
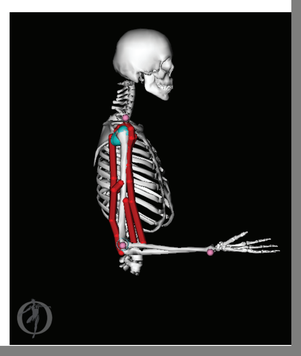


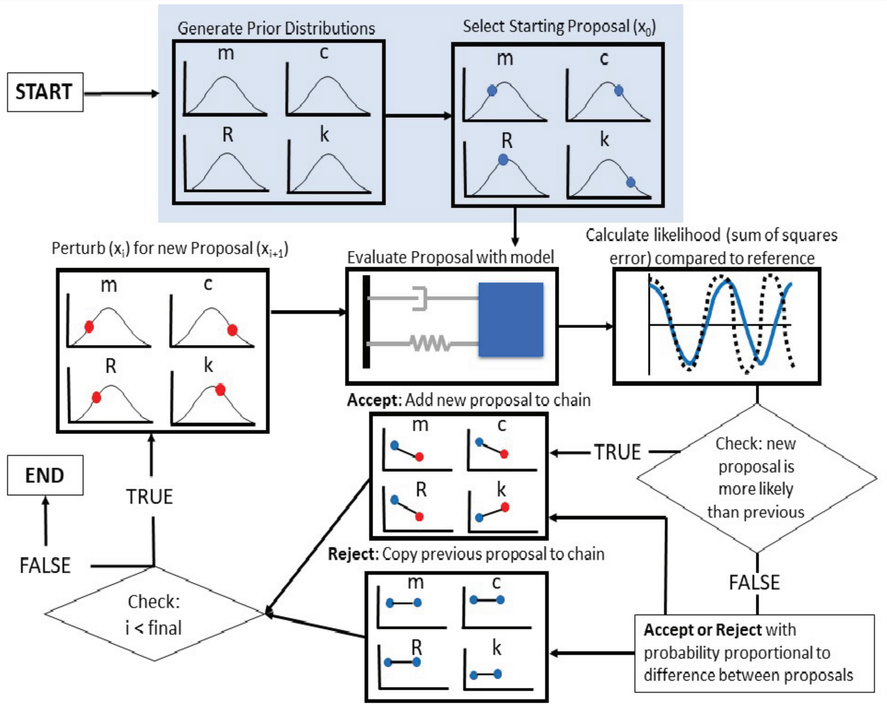
Figure 1: The seven parameters were: mass (M), damping (c), a variable stiffness spring (k1, k2, and R), and initial position (x0) and velocity (xdot0)

- The MCMC algorithm was then used to estimate the plausible muscle excitations for an elbow flexion task given an arbitrarily chosen motion (Fig. 2)

Figure 2: The OpenSim model had a single mechanical degree-of-freedom, and could only flex the elbow using three elbow flexor muscles. The elbow was flexed from 0 degrees to 90 degrees over 0.4 seconds.



MCMC Flow Chart



Results: Mass-Spring-Damper

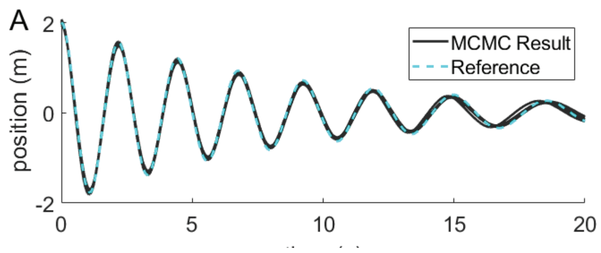


Figure 3: The MCMC algorithm was able to estimate parameters that fit the reference motion

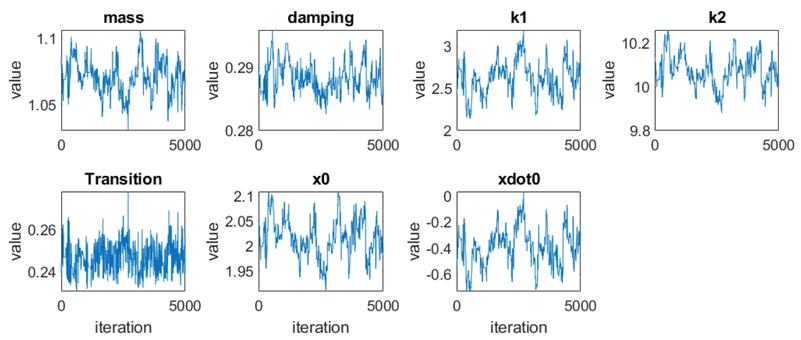


Figure 4: Iteration-series plots for each of the parameters, this shows how the proposals vary throughout each iteration.

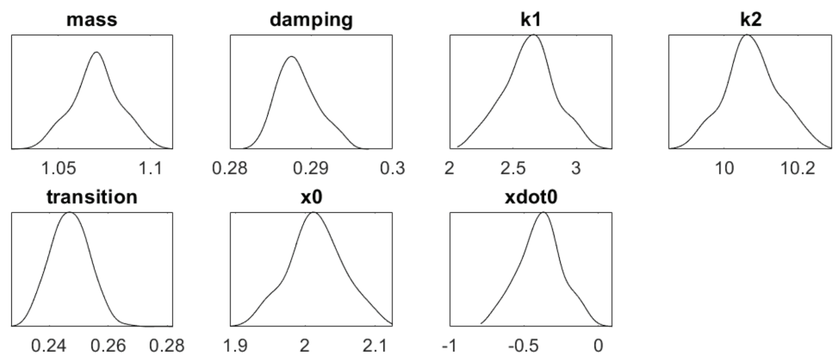


Figure 5: Density plots for showing the likelihood of each of the mass-spring-damper parameters.

Results: Elbow Flexion

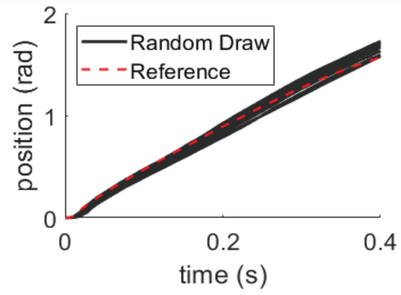


Figure 6: The MCMC algorithm was able to reproduce the reference motion

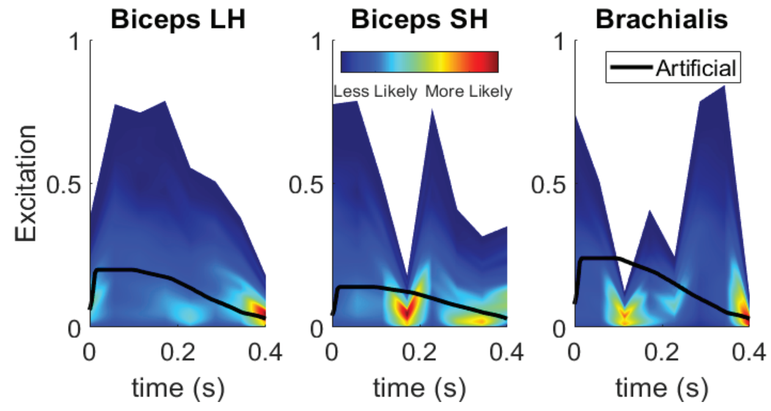


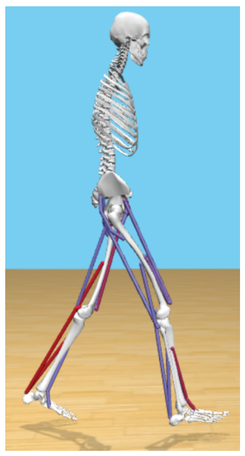
Figure 7: Range of plausible muscle excitations for the three muscles involved in elbow flexion. Muscle excitations were deemed to be more likely if they reproduced the reference motion and reduced the sum of squares of muscle activations.

- Plausible muscle excitations mostly overlapped with the real excitation, except in brachialis

Conclusions and Future Directions

The MCMC algorithm was deemed to be feasible for both the simple mechanical model and the musculoskeletal model.

Future work:
- Estimate plausible muscle excitations during gait.
- Adding priors on objective functions components and measurement error.



References

[1] Myers, et al., Ann. Biomed. Eng., vol. 43, pp 1098-1111, 2015.
[2] Erdemir, et al., Clin. Biomech., vol 22, pp. 131-154. 2007.
[3] Haario, et al., Stat. Comput., vol 16, pp. 339-354, 2006.

Acknowledgements

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