Bayesian estimates of plausible muscle forces in musculoskeletal simulations

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***Abstract*— Quantifying the force generated by individual muscles is difficult for human movements, like reaching or walking, due to the redundancy of the system and many unknown parameters. We propose a Bayesian inference method for estimating muscle forces that accounts for uncertainty at several levels of the analysis. Our initial results indicate that this can give reasonable estimates for simple models. Future work will extend this approach to gait analysis to better understand the range of muscle forces that would be likely for a given measured motion.**

Keywords—musculoskeletal modeling, Bayesian analysis, objective function, Markov Chain Monte Carlo

I. Introduction

Biomechanists are often interested in inferring the timing and magnitude of muscle forces during an observed motion, but accurately determining muscle forces is difficult for several reasons. Musculoskeletal models are commonly used to estimate muscle forces underlying an observed motion, but the estimated forces are sensitive to model parameters that are prone to uncertainties and measurement error inherent in the behavioral data used to estimate segmental kinematics [1]. The estimation of muscle forces is also sensitive to the objective function that is chosen to solve the problem of redundancy [2]. Lastly, validation of musculoskeletal models is challenging because measuring forces *in vivo* is prohibitively invasive.

We propose an approach that transforms physiologically-based hypotheses about muscle force distribution into a Bayesian inference, which can take into account priors on model parameters, measurement uncertainty, and uncertainty in the objective function underlying the behavior. We evaluated the feasibility of using Markov Chain Monte Carlo (MCMC) analysis [3] to: 1) estimate the parameters of a simple mechanical model and 2) estimate the range of plausible muscle forces in a simple elbow flexion task.

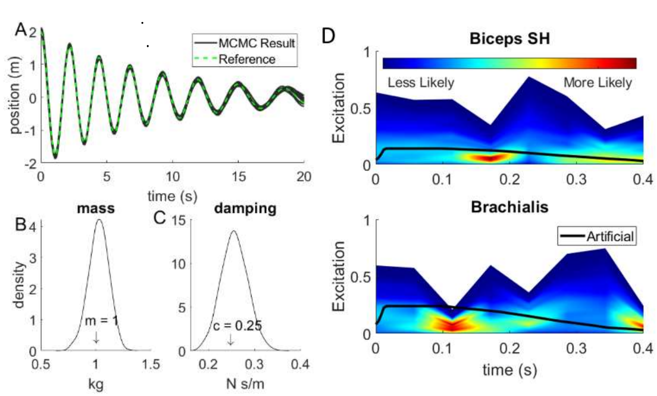

Fig. 1. A) Mass-spring-damper reference motion plotted against 10 random draws from MCMC. B) Density plot of mass of the block. C) Density plot of the damping coefficient. D) Range of plausible muscle excitations for two of the three muscles in the elbow flexion model.

II. Methods

A. Mass-Spring-Damper Model

First, we wanted to test our MCMC approach with a simple, mechanical model. We used a nonlinear mass-spring-damper system with seven parameters defining the mechanical properties of the system and the initial conditions. We simulated the system using arbitrarily chosen parameters and initial conditions. We then used the reference motion as input to the MCMC, where the goal of the algorithm was to estimate the parameters and initial conditions of the simulated system.

B. Elbow Flexion Model

Then, we applied the MCMC algorithm to estimate the possible muscle excitations that could have produced an artificially generated motion in a simple musculoskeletal elbow flexion model with one degree-of-freedom and actuated by three elbow flexor muscles. The reference motion was generated by setting artificial muscle excitations such that the elbow flexed from 180° to 90° over 0.4 seconds. Muscle excitation proposals were deemed more likely by the MCMC algorithm when they were able to reproduce the artificial elbow angle trajectory (sum of square error) and reduced the sum of muscle activations squared.

III. Results and Discussion

A. Mass-spring-damper Model

The MCMC algorithm was able to estimate parameters that fit the reference motion (Fig. 1A) and produced posterior density functions that were centered around the true model parameters (Fig. 1B and 1C). The results were sensitive to the initial proposal, in part due to some of the model parameters being interdependent.

B. Elbow Flexion Model

The MCMC algorithm was able to find a range of plausible muscle excitations (Fig. 1D) that both included the actual excitations and reproduced the reference motion. Future work will expand on these initial results by estimating plausible muscle excitations during gait and adding priors on objective functions components and measurement error.

References

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