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**SIMULTANEOUS DETERMINATION OF SKELETAL MODEL PARAMETER VALUES,  
MOTIONS, AND CONTROLS FROM NOISY MEASUREMENT DATA**

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**INTRODUCTION**

Accurate model parameter value and motion determination is important for obtaining reliable results from inverse dynamics analyses of gait. If the model parameters do not properly match their true values, the predicted motions and loads may lose their clinical significance [1]. Typical approaches to biomechanical model parameter estimation have included the use of scaling rules based on cadaver studies [2] and the use of multi-level optimization routines [3,4]. However, scaling rules do not provide optimal parameter estimates, and multi-level optimization techniques are computationally expensive.

This study examines the use of the Unscented Filter (UF) technique as an alternative method for biomechanical model parameter and motion estimation. The UF is an optimal estimation technique for nonlinear dynamic and/or measurement models that is based on the concept that it is easier to approximate a probability distribution than an arbitrary nonlinear function [5,6]. The approach used here involves applying the UF to the nonlinear motion and measurement equations of a planar, 3 degree-of-freedom (DOF) inverted pendulum model used to represent an idealized moving body. The goal was to obtain optimal estimates for the pendulum model parameters, motions, and control torque simultaneously from noisy marker measurement data and a set of known input ground reaction forces.

**METHODS**

We have developed an approach to estimating unknown biomechanical model parameters, motions, and controls based on the UF. To simulate a moving body during gait, a planar, 3 DOF inverted pendulum model with two motion capture markers was created. The equations of motion for the inverted pendulum model were derived using the Autolev symbolic manipulation software (OnLine Dynamics,

Sunnyvale, CA). Measurement equations were generated for the motion capture markers as functions of the pendulum positions and velocities.

The system was simulated for 5 seconds using a set of known model parameters and ground reaction force and control torque inputs to obtain the true model marker data. The ground reaction forces and control torque inputs were determined from inverse dynamics, where the pendulum translational accelerations were set to zero and the pendulum rotational acceleration was given as

$$Q3'' = -(A\omega^2 I)\cos(\omega t) \quad (1)$$

where  $A = \pi/4$ ,  $\omega = 2\pi$ , and  $I$  was the pendulum inertia. Normally distributed, Gaussian white noise was then superimposed on the model marker data to simulate noisy gait data.

It was assumed that the only information available to the UF in the study was the noisy marker data and the input ground reaction forces. A general dynamics model for the inverted pendulum was assumed with no knowledge of the model parameter values or control torque.

Using only the assumed model, noisy marker measurements, and the known input ground reaction forces, the UF was applied to the inverted pendulum system in a Matlab program (The Mathworks, Natick, MA). Optimal estimates for the unknown pendulum positions, velocities, mass, inertia, length, marker locations with respect to the center of mass, and control torque were obtained.

To obtain an optimal estimate for the control torque, we parameterized the control torque as

$$Tz = B0 + B1\cos(\omega t) + C1\sin(\omega t) \quad (2)$$

where the parameterized coefficients  $B0$ ,  $B1$ , and  $C1$  were considered to be the unknown model parameters of interest. Using the estimated coefficients, the parameterized control torque was calculated.

## RESULTS

The UF was able to accurately estimate the true model motions from the noisy marker data and the input ground reaction forces (Fig. 1). Filter estimates for the pendulum length, inertia, and marker location parameters were all found to be within 1% of their true model values. The UF was unable to accurately estimate the pendulum mass. In addition, the UF was unable to accurately estimate the control torque given in the true system model (Fig.2).

## DISCUSSION

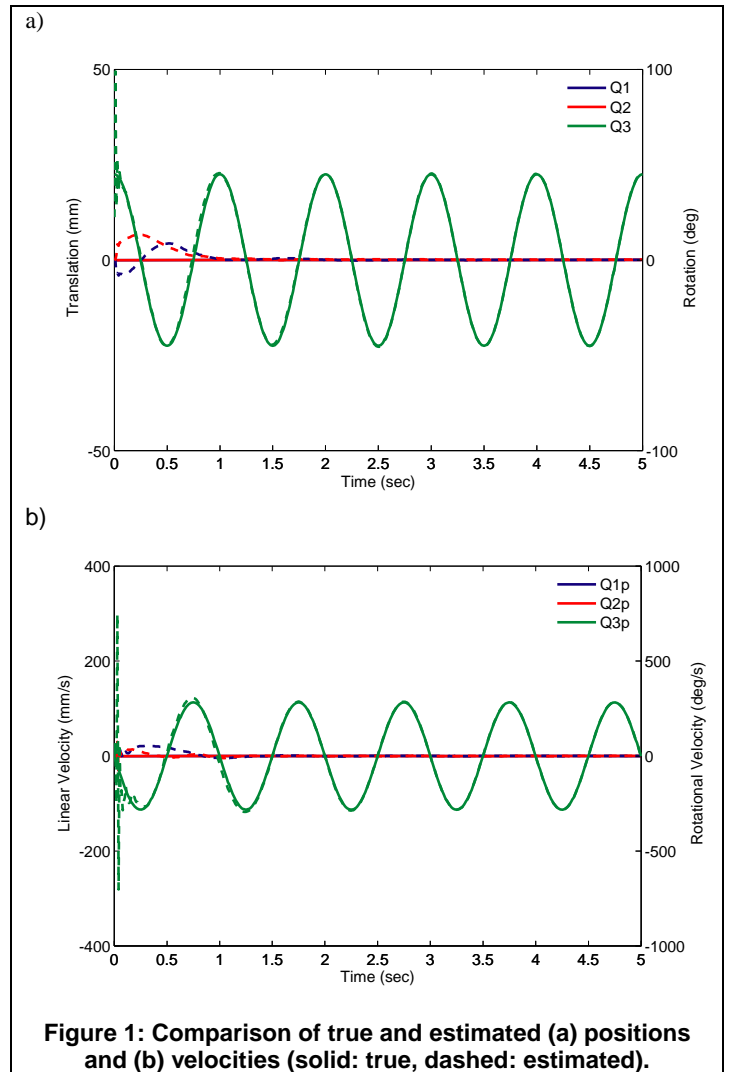
The presented biomechanical model parameter, motion, and control estimation study is based on the optimal performance of the Unscented Filter. The main goal of this study was to accurately and simultaneously estimate the correct pendulum model parameters, motions, and control torque given a set of noisy marker measurements and known input ground reaction forces. The UF was able to accurately estimate all pendulum motions and was able to accurately estimate the pendulum length, inertia, and marker location parameters to within 1% of their true model values. However, the UF was unable to accurately estimate the pendulum mass. This was likely due to the fact that the input ground reaction forces were determined in such a way that the accelerations in the translational DOF were zero. As a result, the system failed to provide a rich enough signal to the filter for proper estimation of the mass. The UF was also unable to correctly estimate the pendulum control torque. This was likely due to the fact that the control torque used to simulate the true model essentially acted like a known measurement, normally obtained from a force plate. In the filter, this known measurement was removed from the system and the parameterized torque was assumed to be another unknown quantity. Therefore, the filter was unable to find optimal estimates for the parameterized torque coefficients.

## ACKNOWLEDGMENTS

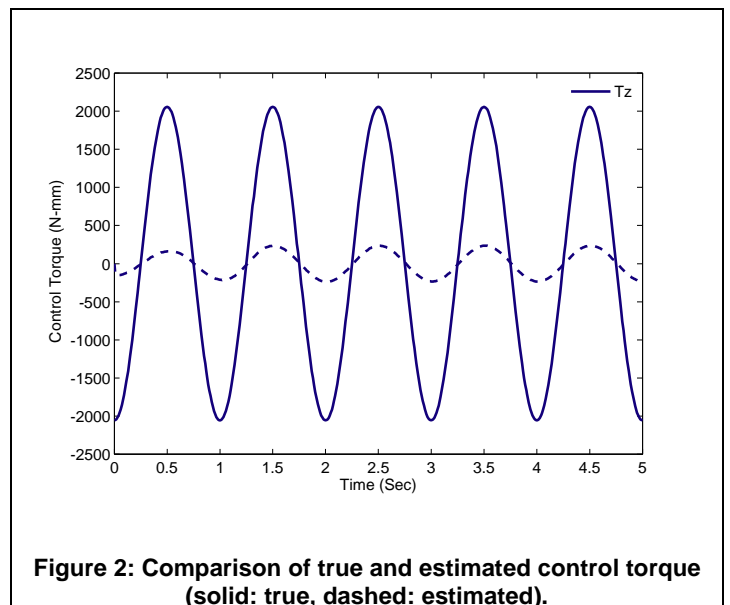
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## REFERENCES

1. Reinbolt, J.A., Haftka, R.T., Chmielewski, T.L., and Fregly, B.J., 2007, "Are Patient-Specific Joint and Inertial Parameters Necessary for Accurate Inverse Dynamics Analyses of Gait?" *IEEE Transactions on Biomedical Engineering*, Vol. 5, pp. 782-793.
2. Bell, A.L., Pedersen, D.R., and Brand, R.A., 1990, "A comparison of the accuracy of several hip center location prediction methods," *J. Biomechanics*, Vol. 23, pp. 617-621.
3. Reinbolt, J.A., Schutte, J.F., Fregly, B.J., Haftka, R.T., George, A.D., and Mitchell, K.H., 2005, "Determination of patient-specific multi-joint kinematic models through two-level optimization," *J. Biomechanics*, Vol. 38, pp. 621-626.
4. Charlton, I.W., Tate, P., Smyth, P., and Roren, L., 2004, "Repeatability of an optimized lower body model," *Gait Posture*, Vol. 20, pp. 213-221.
5. Julier, S.J. and Uhlmann, J.K., 2004, "Unscented Filtering and Nonlinear Estimation," *IEEE Review*, Vol. 92, pp. 401-422.
6. Crassidis, J.L. and Junkins, J.L., 2004, *Optimal Estimation of Dynamic Systems*, Chapman & Hall/CRC, Florida.



**Figure 1: Comparison of true and estimated (a) positions and (b) velocities (solid: true, dashed: estimated).**



**Figure 2: Comparison of true and estimated control torque (solid: true, dashed: estimated).**