Marker Position Determination and Kinematic Analysis of a Patient-specific Musculoskeletal Lunge Model

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INTRODUCTION

Generic musculoskeletal models, developed for inverse dynamic analysis face problems concerning the scaling of the model to patient-specific data and imposing a specific motion to the model. Begin able to automatically adjust parameters in a generic model to match patient-specific data is crucial with respect to decreasing the amount of manual work and to increase the accuracy of the model. This paper demonstrates the application of two methods for kinematic analysis [1] and determination of constant model parameters (local marker coordinates, joint positions/ orientations etc.) [2]. The methods were applied to a forward lunge model used for investigation of ACL injuries.

METHODS

The first method [1] is developed to perform kinematic analysis of a generally described kinematically determinate or over-determinate system. In the case where the system is over-determinate, i.e. has more equations than unknowns, generally the equations cannot be fulfilled. The remedy is to allow some of the equations to be violated and instead be solved "as well as possible". This can be formulated as the following optimization problem:

$$\begin{aligned} \min_{q_i} \quad & G(\Psi(q_i, \hat{p}, t_i)) \\ \text{s.t.} \quad & \Phi(q_i, \hat{p}, t_i) = 0 \end{aligned} \tag{1}$$

where G is a known objective function (e.g. a least-square) of the equations that are allowed to be violated, Ψ (e.g. kinematical drivers such as measured marker trajectories). Φ is the set of equations that have to be fulfilled (e.g. joint constraints), q_i is the system coordinates at the *i*th time frame, $\hat{p}$ is a set of known constant parameters and t_i is the time. From this formulation, it is also possible to derive equations for exact velocity and acceleration analysis [1].
The second method [2] determines constant parameters by solving the following optimization problem for all q_i and a set of unknown constant parameters p for all *N* samples:

$$\begin{aligned} \min_{q_1, q_2, \ldots, q_N, p} \quad & \sum_{k=1}^{N} G(\Psi(q_k, p, t_k)) \\ \text{s.t.} \quad & \Phi(q_i, p, t_i) = 0 \end{aligned} \tag{2}$$

This is indeed a large-scale optimization problem, but, as shown in [2], it can be solved efficiently.
The two formulations were applied to a forward lunge problem used for investigation of ACL injuries. An 18 degree-of-freedom (DOF) generic mechanical model for the lower extremities was developed. Experimental data was obtained by placing external markers on the subject and captured using five video cameras operating at 50 Hz. The optimization problem in equation (2) was then solved by introducing scaling parameters for each segment as the unknown constants and a least-square objective function.

RESULTS AND DISCUSSION

Fig. 1 displays the model after solution of (2), where the objective function was 0.02 m^2 (the squared sum of all marker errors over all samples). Without scaling the objective function was 0.26 m^2. Position, velocity, and acceleration were then calculated and the result of the right knee DOF is displayed in Fig. 2. The peak knee angle during the lunge exercise was -1.92 rad and the peak acceleration of 46.0 rad/s^2 occurred at the 40th sample (toe off).

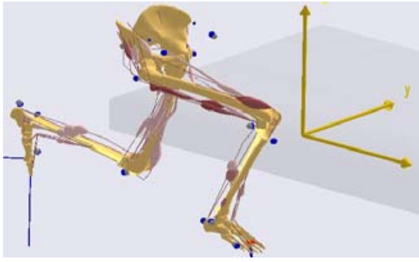

Figure 1: Illustration of the lunge model.

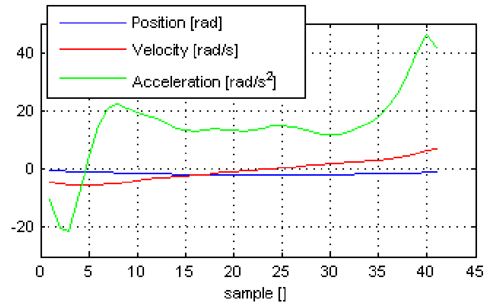

Figure 2: Position, velocity and acceleration for the single right knee DOF.

CONCLUSIONS

Application of two methods for kinematic analysis of over-determinate systems and constant parameter determination were demonstrated. The general formulations presented allow for kinematic analysis and parameter adjustment of arbitrary over-determinate rigid-body mechanical systems subject to holonomic constraints. The methods can streamline the process of applying marker-based movements to musculoskeletal models and improve the accuracy of the analysis.

REFERENCES

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2. Andersen MS, et al. *Scaling and local marker coordinate determination for musculoskeletal systems.* Digital Human Modeling for Design and Engineering, 2007. (Submitted)