BAYESIAN FILTERING AND SMOOTHING TECHNIQUES IN HUMAN MOTION ANALYSIS

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INTRODUCTION

During motion analysis the movement of the human body is derived from the position of surface mounted markers. The most important sources of measurement errors are soft tissue artifacts (STA) and noise. A generic model underlies the data processing. The degrees of freedom of the model are represented by the generalized coordinates q. During inverse kinematics, the traditional approach, an estimate of q is obtained by a nonlinear least squares fit between the model and the measurements of the markers. Since this approach estimates q at each time step separately, the a priori knowledge that human movement is smooth can inherently not be included. Further, numerical differentiation of q leads to exploding errors on q' and q'' and will therefore influence the joint reaction moments and forces. In contrast Bayesian filtering and smoothing techniques, which are proposed in this abstract, allow us to use the knowledge about the smoothness of the movement and to estimate q' and q'' along with q.

METHODS

Bayesian filtering and smoothing techniques are based on a process model and a measurement model. The process model, used for prediction, describes the joint movement. The measurement model, used for correction, describes the relation between the states (q, q' and q'') and the measurements (the marker positions) and is based on the musculoskeletal model provided in SIMM (Delp, 1990). Modeling and measurement errors are accounted for by considering well chosen uncertainty in both process and measurement models. The states are estimated along with a covariance, reflecting the reliability of the estimate.

This abstract fits in a study exploring multiple aspects of Bayesian techniques:

- the suitability of different filtering and smoothing techniques, for example extended Kalman, unscented Kalman, nonminimal Kalman;
- the influence of the underlying process model, for example constant velocity, constant acceleration, periodic movement;
- the possibility to include STA in the underlying model;
- extra features offered by the Bayesian framework: model prediction and interpolation in the case of temporarily incomplete measurements and the detection of marker detachment.

The developed framework is first validated in simulation and is thereafter applied to and evaluated on experimentally obtained gait data. In simulation, STA are modeled by a systematic error on the simulated measurements proportional to the value of the generalized coordinates with an order of magnitude of 10mm over the motion range. Measurement noise is simulated by corrupting the simulated measurements with Gaussian noise with mean 0 and standard deviation 1mm. In a simulated environment the true values of the states are known, allowing a comparison between the estimation errors on the least squares estimates and on the Bayesian estimates. In the experimental case, the estimations are based on part of the measured markers, whereas the other markers are used as validation markers. The positions of these validation markers are calculated from the state estimates. The discrepancy between the calculated and measured positions of the validation markers is a measure for the quality of the state estimation.

RESULTS AND DISCUSSION

In simulation, the root mean square (RMS) error of the Bayesian estimates is 20 percent smaller than the RMS error of the least squares estimates. Figure 1 shows the value of the horizontal translation of the pelvis in the frontal plane used for simulation along with the least squares and Bayesian estimates.
For the experimental gait data, the RMS and peak deviation of the calculated (based on the estimate of q) positions from the measured positions of the validation markers are respectively 25 and 35 percent smaller for the Bayesian estimates than for the least squares estimates. The covariance on the estimations is biggest for the hip rotations, which is in accordance with the expectations.

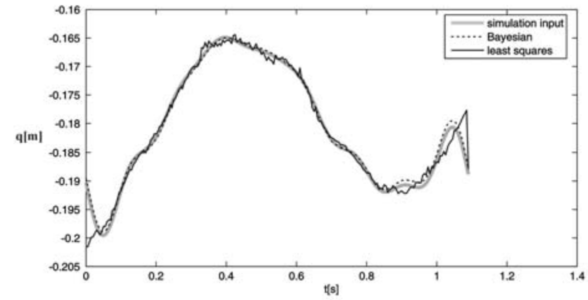

Figure 1: the value of the horizontal translation of the pelvis in the frontal plane used for simulation along with the least squares and Bayesian estimate as a function of time

CONCLUSIONS

This research is related to the calculation of the joint kinematics from measured body-surface marker positions during human motion, a first and essential preprocessing step in motion analysis. Our results show that the use of Bayesian filtering combined with smoothing techniques, incorporating the smoothness of the human body, substantially improves the estimate of the joint kinematics as compared to the currently used techniques.

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