BIOMECHANICAL MODELLING FOR COMPUTER-ASSISTED SURGICAL PLANNING

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INTRODUCTION

Forward-dynamic (FD) biomechanical models are ideally suited to computer-assisted surgical planning (CASP) as they allow the effects of changes to the musculo-skeletal system to be studied with no *a priori* knowledge of post-operative kinematics. Furthermore, the interpretation of movements as output in terms of patient function is straightforward. Conventional forward-dynamic models try to optimise the neural inputs needed to drive the model, which can lead to impractically long simulation times. For large-scale models, which are essential for realistic modelling, a week on a supercomputer would not be unrealistic. An efficient method for the optimisation of FD musculo-skeletal models combining inverse and forward dynamics is described in this study. This method allows the use of large-scale, forward-dynamic biomechanical models in computer-assisted surgical planning and has been applied to a model of the shoulder and elbow (DSEM). The method described features an efficient algorithm for the calculation of the neural inputs necessary for the simulation, which will lead to clinically feasible simulation times.

METHODS

The works of Helm (1994) and Happee and Helm (1995) are taken as the starting point for this study. This work has been extended to produce a 17 degree-of-freedom model with 31 muscles represented by 139 actuators. Geometrical data (including muscle architecture properties) are taken from the cadaver studies of Klein-Breteler (1999).

The method involved a pre-processing stage to calculate the neural inputs for a given motion which is done using a modified form of the inverse-dynamic model: inverse-forward-dynamic optimisation (IFDO). This is an inverse-dynamic optimisation, but with increased constraints on the load-sharing problem due to muscle dynamics being included. Muscle state variables at time-step *i-1* are integrated using a forward muscle model to calculate minimum and maximum muscle forces at time-step *i*. These values then form the bounds of the muscle force optimisation. An inverse muscle model is then used for the calculation of neural inputs from these forces. These neural inputs are then used to drive the model from step *i-1* to step *i* in FD mode. Differences between the resulting motions from the FD model and the measured motions can then be used to correct the calculation of neural inputs at time-step *i*. This is known as IFDO with controller, or IFDOC, and is shown in Figure 1.

This results in an optimal set of neural inputs for a given motion. These neural inputs are subsequently used to drive the model in forward-dynamics mode. The FD model is described in van der Helm (2002). The effects of small changes to the musculo-skeletal system on the resulting kinematics can then be studied. Together with detailed knowledge of individual patient geometry obtained from imaging studies, this allows the optimisation of a procedure for a given patient.

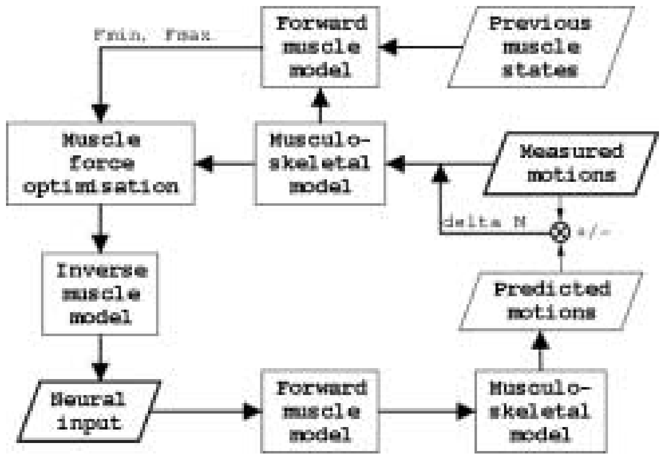

Figure 1 FODC scheme

RESULTS

The success of the IFDOC method is judged by the ability of the model to reproduce measured motions. In a static test (where the model was required to maintain 90° of shoulder abduction), the fluctuation of the forward-dynamic model about the reference line was less than 0.1° with the use of the controller.

The forward dynamic simulation of 600 ms of movement was completed in approximately 18 minutes on a 500MHz Pentium III. An Euler integration method with a time-step of 1ms was used.

DISCUSSION

As there is no optimisation during the FD stage, the simulations are relatively fast, compared to the 1 week mentioned above. Changes to the model can be made (virtual surgery) using an intuitive graphical user interface, and their effect on the predicted motions studied, making the model useable as a Computer-Assisted Surgical Planning tool.

Future work will involve the validation of the model in patient trials, and integration of the model into an intuitive Computer Assisted Surgery package.

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