Extended Abstract

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Comparison of forward-dynamics approaches to estimate muscular forces in human gait

Florian Michaud[1], Urbano Lugris[1], Ye Ou[2], Javier Cuadrado[1] and Andres Kecskemethy[2]

[1] *Lab. of Mechanical Engineering, University of La Coruña, {florian.michaud, ulugris, javier.cuadrado}@udc.es*
[2] *Institute of Mechanics and Robotics, University of Duisburg-Essen, andres.kecskemethy@uni-due.de*

In a previous paper [1], the authors presented a comparison among four muscle recruitment criteria working on a static optimization scheme, and an additional criterion applied within a physiological optimization approach. However, all these methods were based on an inverse dynamic analysis of the acquired motion, which provided the joint drive torques that had to be produced by the muscles considered in the model.

It is well-known that using a forward-dynamics approach to find the excitation patterns that best generate movement trajectories has the best potential to provide insight into muscle coordination. Even though the forward and inverse dynamics models are identical, the estimated muscle forces or optimal excitations by inverse-dynamics approaches hardly reproduce the measured movement in a forward dynamic simulation due to both errors from the estimation of intersegmental moments by inverse dynamics and errors from numerical integration.

Hence, in this work the authors compare several methods which are based on a forward-dynamics approach. All of them are applied to the gait of a female subject of 50 kg weight and 1.67 m height that was captured (along with the ground contact forces) and used, after signal processing, to animate an 18-segment three-dimensional model with 57 degrees of freedom (Figure 1, left and center) by means of an in-house developed software. In the right leg of the model, 43 muscles were considered (Figure 1, right), their properties taken from [2].

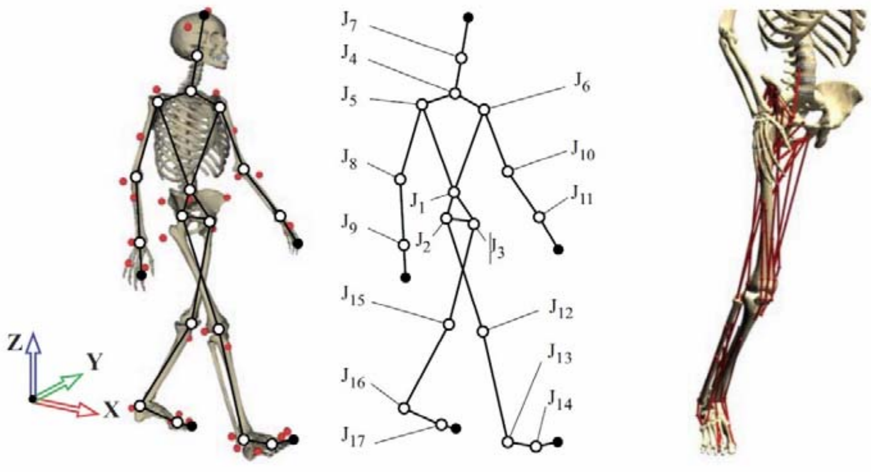

Fig. 1: 3D human model and detail of muscles on the right leg.

The first method makes use of Computed Torque Control (CTC) to obtain the joint drive torques that best approximate the acquired motion at each time step and, then, in the joints where muscles have been modeled, applies the physiological optimization proposed in [1], with the difference that the joint drive torques are no longer introduced as constraints, but included in the cost function along with the muscle recruitment criterion. The selection of the weighting factors gives priority to the fulfillment of the torque conditions.

The second method is an adaptation of the one proposed in [3] (the adaptation being that CTC is used at skeletal level), which starts by carrying out the integration of the muscle contraction equations for maximum activation and, then, obtains the muscle forces by static optimization assuming a linear relationship between muscle force and activation.

The third method is called physiological inverse muscle excitation approach [4]. It makes a first prediction loop, which is basically the same scheme described above for the first method, but considering the discrepancy between the current acquired trajectories and the simulated ones in the previous time-point. The resulting excitations are used as inputs for the simultaneous integration of activation, contraction and motion equations, thus yielding the predicted states. Then, a second correction loop is performed, which repeats the process with the predicted current simulated trajectories substituting those from the previous time-point, and provides the final corrected states.

The fourth method is the well-known Computed Muscle Control (CMC) [5]. It is similar to the previous one, but limited to one single loop. Furthermore, the cost function is based on volume-weighted muscle activations instead of muscle forces.

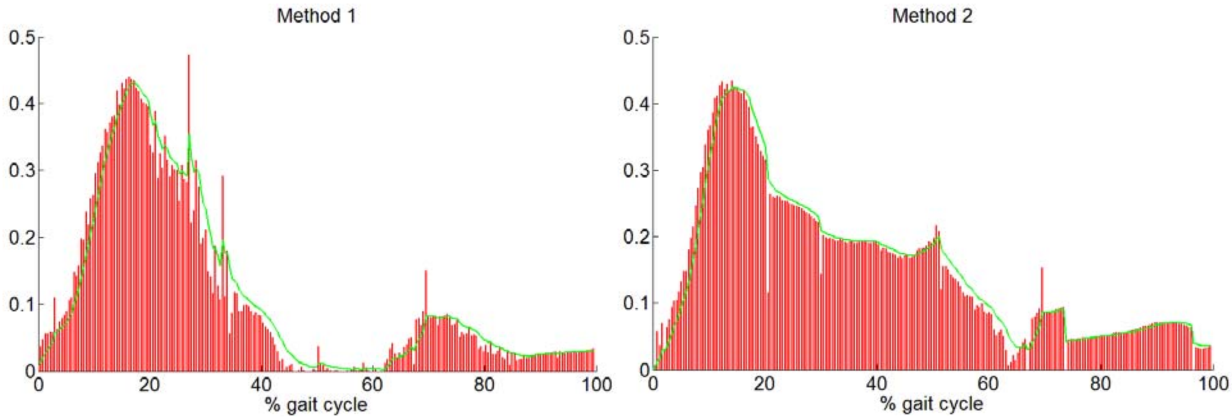

Fig. 2: Excitation (red) and activation (green) of gluteus maximus superior for two of the methods.

Figure 2 shows the excitation and activation histories obtained for the gluteus maximus superior with the first and second methods described above. In the paper, the efficiency and accuracy of the four methods are compared. Accuracy is evaluated as the correlation between the acquired motion and the motion provided by the forward dynamic integration of the model with the obtained excitations as inputs. Attention is also paid to the results of muscular forces, activations and excitations, and their correlation with the data provided in the literature.

References

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