Muscle parameter identification by using an artificially activated muscle model

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Abstract

One of the most recurrent problems in biomechanics is the estimation of muscle forces. Different approaches have been developed to that end using forward or inverse methods. The validation of the obtained results is still a challenge: direct measurements require a highly invasive procedure; on the other hand, indirect methods depend on a set of muscle parameters obtained from cadaver studies [1] or medical imaging [2]. Moreover, those parameters must be scaled according to the anthropometry of the test subject. Other authors propose different approaches based on EMG-driven models [3] that reproduce the physiology of the process, however, the repeatability of the test is not ensured as the movement depends on the neural signals commanded by the subject and these may vary between tests.

In this work, we adjust the muscle parameters by using an artificially activated muscle model in an inverse dynamics approach. The system input is a known and controllable signal applied by functional electrical simulation (FES) and the output is the FES induced kinematics of the multibody system, in this case the leg of the subject. We perform an inverse dynamics analysis (IDA) on the obtained kinematics to calculate the muscle activations, and then the stimulation profile that produce that movement. Muscle parameters can be obtained by minimizing the difference between the predicted and the applied excitation signal. A modified Hill-type muscle model that considers the applied stimulation is used in this work [4]. As the stimulation process only affects the muscle fibre recruitment, only the activation dynamics changes with respect to a physiologically activated muscle. The muscle dynamics can be expressed by means of two differential equations cascaded:

$$k_1 \cdot \ddot{a}(t) + k_2 \dot{a}(t) + a(t) = e(t) \tag{1}$$

$$\dot{F}^m(t) = h\big(a(t), F^m(t), l^m(t), \dot{l}^m(t)\big) \tag{2}$$

where $a(t)$ represents the activation signal, $e(t)$ is the excitation signal that accounts for the stimulation parameters, F^m is the muscle force, and lastly, l^m and $\dot{l}^m$ are the muscle length and contraction velocity respectively.

The proposed approach is represented in Figure 1. From the acquired kinematics it is possible to calculate net joint torques and net joint reaction forces by applying the equations of motion:

$$\begin{cases} \mathbf{M}\ddot{\mathbf{q}} + \mathbf{\Phi}_{\mathbf{q}}^{T}\boldsymbol{\lambda} = \mathbf{Q} \\ \mathbf{\Phi}(\mathbf{q}, t) = 0 \end{cases} \tag{3}$$

where $\ddot{\mathbf{q}}$ is the accelerations vector, $\mathbf{M}$ is the mass matrix of the system, $\mathbf{Q}$ is the generalized forces vector, $\mathbf{\Phi}$ is the vector of constraint equations, $\mathbf{\Phi}_{\mathbf{q}}^{T}$ is the transposed Jacobian matrix of the constraints equations and $\boldsymbol{\lambda}$ the Lagrange multipliers vector. By means of an optimization method it is possible to

compute muscle forces from the previous results. Then, from Equation (2) it is possible to calculate muscle activations. By using equation (1) the stimulation profiles can be estimated to be compared with the applied ones. The inverse dynamic analysis is performed in Opensim [5] as it is a widely used and validated tool in the biomechanics community.

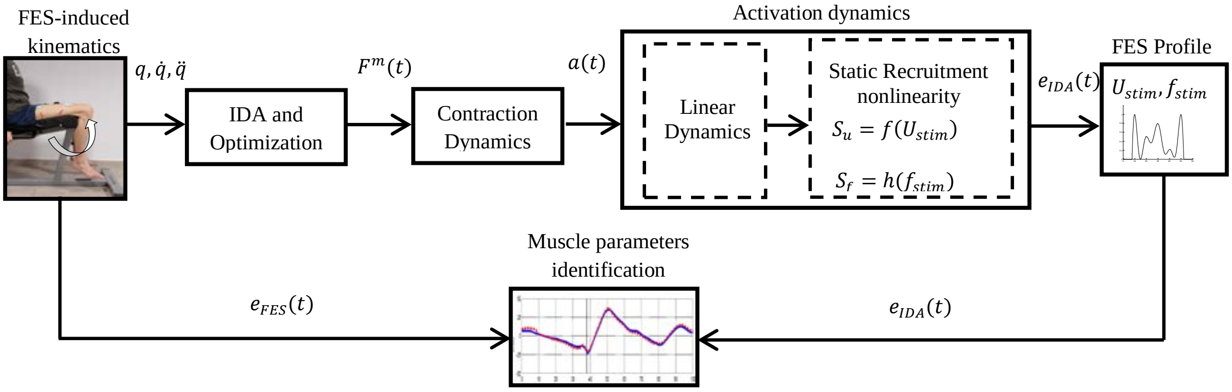

Figure 1: Schematic representation of the different stages to optimize muscle parameters by using an artificially activated muscle model in a forward approach.

The last step is to minimize the following cost function to obtain muscle parameters:

$$\min \quad J = \frac{1}{2}\sum_{j=1}^{N}\left(e_{IDA}(PCSA, l_0^m, l_0^T, \alpha) - e_{FES}\right)^2 \tag{4}$$

where e_{IDA} is the excitation signal obtained by represents the kinematics obtained by the IDA, e_{FES} corresponds to the applied stimulation and $PCSA$, l_0^m, l_0^T and α are the muscle parameters (physiological cross sectional area, optimal fibre length, tendon slack, length and pennation angle respectively). The kinematics was recorded using 12 infra-red light cameras OptiTrack V100:R2 at 100 Hz, synchronized with the stimulator (HASOMED RehaStim).

The obtained results are expected to contribute in the field of muscle parameter identification, allowing a subject specific tuning. Furthermore, once the model is validated, it could be possible to synthetize subject specific FES stimulation profiles for rehabilitation purposes. Indeed, the prescribed stimulation program may be applied in the design of control strategies in assistive devices such as hybrid orthoses.

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