Fast Optimization Scheme for the Muscular Response to FES Stimulation to Design a Smart Electrostimulator

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We present the design of a smart electrostimulator for muscle rehabilitation or reinforcement, using fast computations, in order to control the muscular force. The Ding and al. model allows to predict and to optimize the muscular force response to functional electrical stimulation. [2]. The controls are the frequency and amplitudes of the electrical stimulations. They fit in the sampled-data control category [5]. The goal is to maximize the force response or to track a force of reference [1].
In previous references [3], [4] the problem was analyzed using direct or indirect optimal control schemes which are computationally expensive due to the numerical integration of the dynamics. In a more recent work we derive an approximation of the force response in [5] which depends upon the 6 parameters of the Ding's model and which can be used to derive a fast optimization scheme in this category by bypassing the time computational expensive integration of the dynamics of the Ding and al. equations.
The experimental validation of the model requires the estimation of its parameters. Several methods are proposed. First, we analyze the estimation of the Ding and al. parameters using an approximation of the force response [5] which depends upon the 6 parameters of the Ding's model.
An online estimation of the parameters of the approximation of the force response to a train of pulses is presented. The choice is made for an online estimation by optimization, especially in the case of an embedded muscle stimulator for computation time issues. The force measurement data are fitted to the force model.
Finally, we present the implementation of a non-linear observer for the estimation of the parameters of the muscle fatigue model. This approach is based on measurements that justify the different treatment of the fatigue parameters compared to the other parameters estimated differently by optimisation.

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[2] A. W. J. Ding, S. Binder-Macleod. *Development of a mathematical model that predicts optimal muscle activation patterns by using brief trains.* J. Appl.Physiol., **88**, 2020.

[3] L. B. J. R. T. Bakir, B. Bonnard. *Pontryagin-type conditions for optimal muscular force response to functional electrical stimulations.* J. Optim. Theory Appl., **184**, 2020.

[4] L. B. J. R. T. Bakir, B. Bonnard. *Direct and indirect methods to optimize the muscular force response to a pulse train of electrical stimlation.* ESAIM : Proceedings and Survey, EDP Sciences, **71**, 2021.

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