REAL-TIME FATIGUE TRACKING USING ELECTROMYOGRAPHY DRIVEN MUSCULOSKELETAL MODELS

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Abstract

Real-time Electromyography driven neuromusculoskeletal models can provide a robust approach to control wearable assistive devices over a wide repertoire of movements. However, the models are not designed to track changes in muscle activity due to fatigue, and would fail to provide a realistic estimate of joint torques in these situations. Here, we describe a fatigue model that can be appended to Hill-type neuromusculoskeletal models for real-time tracking of joint torques. This opens up a new type of human-machine interfaces that allow steering biomechanical parameters away from fatigue in addition to providing assistance during movement.

Introduction

Robust human-machine interfacing requires intuitive controllers that allow users to move in a wide repertoire of movements. This is crucial for wearable exoskeleton design. Real-time Electromyography driven neuromusculoskeletal models (uENMS-RT) have been shown to be robust controllers for providing assistance using ankle exoskeletons [1,2]. The ability of uENMS-RT to decode biological joint torques is enhanced by user specific calibration of musculoskeletal parameters. Once calibrated, the uENMS-RT requires only joint angles and muscle activity measurements which can be implemented in a minimal wearable approach [2].

However, the uENMS-RT does not account for changes in muscle activity due to fatigue. Thus, with continuous prolonged use or after fatiguing tasks, the user specific model may need to be revisited [3].

Fatigue models have been added to neuromusculoskeletal models for improving joint torque estimation during functional electrical stimulation [4] or modeling age related changes [5]. However, these models aim to accurately represent changes in biochemical compositions of fatigue, and are not suitable for user specific modeling of joint torques.

Thus, here, we describe a fatigue model that can be included to the uENMS-RT for real-time tracking of joint torques and control of human-machine interfaces. The proposed approach is aimed at user specific modeling of fatigue.

Design of user specific fatigue model

$$F^{mt} = F^{t} = F^{m} \cdot \cos\left(\phi\left(\tilde{l}^{m}\right)\right) \quad (1)$$

$$F^{m} = F^{max} \cdot \left[a(t) \cdot f\left(\tilde{l}^{m}\right) \cdot f\left(\tilde{v}^{m}\right) + f\left(\tilde{l}^{m}\right) + d^{m} \cdot \tilde{v}^{m}\right] \quad (2)$$

$$\tau^{jt} = \sum_{mt} \left(F^{mt} \cdot ma^{mt}\right) \quad (3)$$

$$F^{act} = F^{max} \cdot e^{(-K\alpha)};\ \tilde{v}^{act} = \tilde{v}^{max} \cdot e^{(-K\alpha)} \quad (4)$$

$$\alpha = \frac{1}{t_p} \int EMG \cdot dt \quad (5)$$

The uENMS-RT is based on Hill-type models [6,7] (Eqn 1, 2, 3). The muscle tendon force F^{mt} is the same as tendon force F^{t} and muscle force F^{m} scaled by cosine of the pennation angle ϕ which depends on the optimal fibre length ($\tilde{l}^{m}$). Eqn. 2 relates F^{m} and maximum isometric force F^{max}, activation dynamics (a(t)), force-length and force-velocity relationship, and a damping factor (d^{m}). The joint moments (τ^{jt}) are derived from F^{mt} and moment arm (ma^{mt}) of the MTU across the joint (Eqn 3). Peripheral fatigue reduces the F^{max} and peak contraction velocity ($\tilde{v}^{max}$) exponentially [8]. Therefore, the actual F^{max} and $\tilde{v}^{max}$ are modelled using Eqn (4). They are both scaled by a muscle specific fatigue index α and a user specific fatigue index K. α is integrated EMG scaled by $\frac{1}{t_p}$, where $t_p$is time passed since the activity in minutes. K is found in [0, 1] by minimizing $\tau_{model} - \tau_{ID}$.

Proposed Protocol and Discussion

Recruited participants will perform calibration, fatigue, and a real-time tracking protocols. During calibration, a user specific OpenSim model and uENMS-RT model will be setup from motion capture system, electromyography, and force plate data [2]. The fatigue protocol will be used to estimate the user specific fatigue parameters α and K. Finally, in the real-time phase, the users will perform walking tasks and the validity of the uENMS-RT to assess joint torques will be assessed. This will be a first study to track user specific joint torques accounting for user specific changes to muscle activity due to fatigue. Progress on this study will be shared at the conference.

References

1. Durandau et al, *IEEE TBE*, 65: 556–564, 2018.
2. Durandau et al, *IEEE TRO*, 38:1380–94, 2022.
3. Mohamed Refai et al, Abstract 27th ESB, 2022.
4. Giat et al, *IEEE TBE*, 40, 1993.
5. Callahan et al, *J. Physiol.*,594:3407–21, 2016.
6. Hill, *J. Physiol.*, 56:19–41, 1922.
7. Caillet et al, *bioRxiv*, 2022.
8. Devrome and MacIntosh, *J. Appl. Physiol.*, 125:706–14, 2018.

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