Modeling Fatigue Effect in an EMG-Driven Hill Type Muscle Model during Dynamic Contractions*

Diana. R. Bueno and L. Montano

Aragón Institute of Engineering Research (I3A), and with the Department of Computer Science and Systems Engineering, University of Zaragoza, Spain
{drbueno,montano}@unizar.es

Abstract. Since appearance of fatigue is a reality in rehabilitation sessions, developing a muscle model that is able to cope with this effect in dynamic contractions is a must. In this paper we attempt to model the effect of fatigue in a Hill type muscle model with weighting sum of joint torques. Focus on an upper limb movement to evaluate the model, specifically an elbow flexion-extension, the promising results will contribute to achieve a generalized model that is able to mold to different movement conditions.

1 Introduction

Motor rehabilitation can be improved with the use of robotic exoskeletons under the *'assist-as-needed'* paradigm. This is the framework of HYPER project [7], developing Hybrid Neuroprosthetic (NP) and Neurorobotic (NR) devices for functional compensation and rehabilitation of motor disorders. Based on this need we are working on a Neuroestimator (NE) under this paradigm so with dynamical adaptations according to the latent motor capabilities of the users. The NE captures the sensor signals from the different neural, physiological and physical sensors, and integrates them to estimate the variables and control parameters and achieve a functional interpretation.

The results in [8] set the basis and motivation of this work. The analysis of the behavior of the Hill Based model in different movement conditions reveals meanly how bad the model is adapted in fatigue states. The aim of this paper is to adapt our Hill type model to fatigue conditions in order to obtain a more generalized muscle model. Achieving this purpose we would be able to mold it to every subject or clusters of population in different conditions.

* This study has been partially funded by the Spanish project HYPER CSD2009-00067 and the project DGA-FSE- 2012T-04.

J.L. Pons et al. (Eds.): *Converging Clinical & Engi. Research on NR*, BIOSYSROB 1, pp. 341–345.
DOI: 10.1007/978-3-642-34546-3_54

The rest of the paper is organized as follows: Section 2 introduces an approach to model the fatigue effect. Section 3 details the equipment and methodology. Results are described in Section 4 and Conclusions are presented in Section 5.

2 Modeling the Fatigue Effect

An EMG-driven model has processed EMG signal as input. This neural signal is characterized as being non-stationary during dynamic contractions. While the EMG amplitude is increased when muscle is affected by fatigue, the mean frequency of the signal reflects a decrement. [4] describes a state of art of the fatigue evaluation. Among the large number of methods reported there, Choi-Williams transform time-frequency technique seems to be the most adequate [6]. However, it is worth mentioning that Dimitrov spectral index is currently proposed as a new reliable metric for assessing fatigue in dynamic tasks [5].

To our knowledge, although several studies about muscle fatigue have been developed, there is a lack of studies trying to redesign muscle models in fatigue state. Recently, [1] proposes a proportional factor to muscle gain in a methodology that computes knee joint moments under dynamic conditions using EMG combined with non-linear constrained optimization. Parallel to this idea, we approximate the effect of muscle fatigue by a weighted sum of moment contributions (1), (2).

$$\widetilde{M}_i^{nf} = \sum_{i=1}^{n} r_i \times \tilde{F}_{T_i} \quad (1)$$

$$\widetilde{M}^f = \sum_{i=1}^{n} \omega_i^{F/E} \, \widetilde{M}_i^{nf} \quad (2)$$

Where $\widetilde{M}^f$ stands for the estimation of the net moment in a joint under fatigue conditions, $\widetilde{M}_i^{nf}$ represents the moment estimated through Hill-Based models optimized for each subject in non fatigue conditions, n is the number of muscles that we take into account, $\omega_i^{F/E}$ is the weighting factor for muscle *i* for flexion and extension movement separately, $\tilde{F}_{T_i}$ is the total force exerted by muscle *i* obtained from the used model, and r_i is the moment arm of each muscle given by [2] and [3]. The weighting factor and the physiological model parameters are calculated through optimization techniques. The fatigue level has to be estimated on line in order to apply this level to adapt the model parameters during the motion. Time-frequency techniques as above mentioned can be used to obtain a correlation between the weighting factor and the fatigue metric.

3 Material and Methods

3.1 Subjects and Equipment

Four healthy male subjects, 25-31 years old, average weight and height of 78 ± 15.75 Kg and 175 ± 5 cm.

KENDAL Meditrace 200 EMG sensors were used, placed in accordance with SENIAM (European project: Surface EMG for Non-Invasive Assessment of Muscles) on 8 muscles. The signals were amplified using a commercial gTec system. The EMG was digitized at 2.4KHz, power-line notch-filtered at 50Hz, and bandpass filtered at 5/500Hz. The data processing is described in [8].

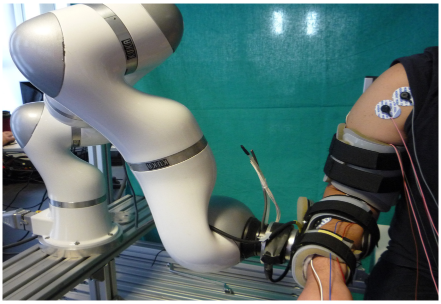

Fig. 1. A LWR KUKA robot was used as an experimental exoskeleton and an ATI Gamma force/torque sensor placed on the end-effector, to estimate the real elbow torque to be compared with that obtained by our NE.

3.2 Experimental Protocol

The trajectory movement was an elbow flexion/extension (0-110º range). The experimental protocol consists of: 1) Isometric Maximal Voluntary Contraction (MVC) session. 2) Dynamic non fatigue session for basic non-fatigue model calibration: Four flexion/extension movements for each level of robot's resistance force: 50%, 75%, 98%. 3) Isometric fatigue session: the subjects had to hold a dumbbell in a 90ª flexion position for as long as they could. 4) Dynamic fatigue session: subjects perform the same exercises as in the dynamic non fatigue session.

4 Results

To simplify the study, we start from the fatigue dynamic session, which implies we do not manage directly estimation of the level of muscle fatigue online. Once the physiological parameters of the muscle model are calculated according to [8] with non fatigue sessions (step 2 of the protocol), the adjusting process of the weighting factors for the fatigue state works as follows: we have studied fatigue effect in the model during flexion and extension separately. At the beginning of the session, the weighting factors for flexion are optimized with the first flexion trial and, in a similar manner, the weighting factors for extension are optimized with the first extension movement. A nonlinear 'trust-region-reflective' algorithm from the Matlab Optimization toolbox has been employed in the process. The other data were used to validate the approach. Fig 2 and Fig. 3 show some of the results obtained taking into account the effect fatigue in our Hill type model compared to the results obtained in [8]. As can be seen in Fig.2, the extension trial of subject 4 at 50% of robot resistance, the maximal error (E_{max}) can be reduced up to 41% and the root mean square error up to 46%. Fig. 3 represents for each subject the mean and standard deviation of the maximal error of the three flexion trials at 50%, 75% and 98% of robot resistance. The maximal error is reduced in each case.

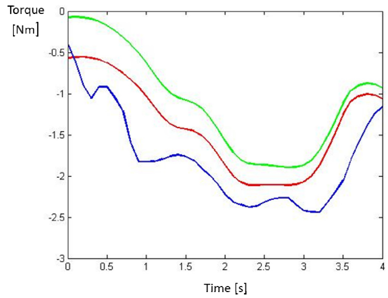

Fig. 2 Extension trial in fatigue conditions of subject 4 at 50% of robot resistance. Blue line depicts the force sensor measurement. Green line is the estimations without taking into account the weighting factors. The result of the purposed approach is represented by a red line.

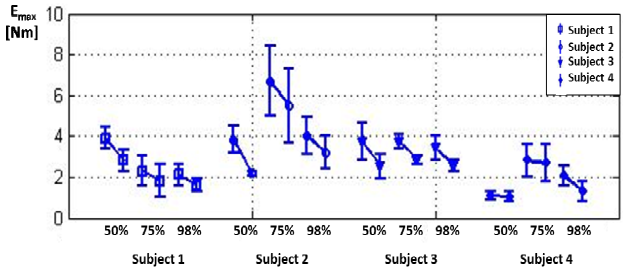

Fig. 3 Mean and standard deviation of Emax for different robot resistance levels with fatigue and in flexion movement. For each resistance level the first error bar belongs to the model without taking into account fatigue effect and the second one belongs to the weighting sum model.

5 Conclusion

In this work we propose to model the fatigue effect in a Hill Based muscle model. Based on the idea presented in [1] that takes heed of the decrease of the moment generation capacity with fatigue, we propose an optimized weighted sum approach to take into account the variation of moment production when a subject is required to carry out the same task (remaining identical robot force resistant and elbow joint trajectory) in both, non fatigue and fatigue conditions.

With four subjects, a representative decrease in error estimations is obtained. These promising results will contribute to achieve a more adaptive and general muscle model to be applied in a NR/NP during a rehabilitation session. As future work we will evaluate the performance of this novel approach in patients with motor disorders.

References

[1] Rao, G., Berton, E., Amarantini, D., Vigouroux, L., Buchanan, T.S.: An EMG-Driven Biomechanical Model That Accounts for the Decrease in Moment Generation Capacity During a Dynamic Fatigued Condition. Journal of Biomechanical Engineering 132 (July 2010)

[2] Delp, S.L., Anderson, F.C., Arnold, A.S., Loan, P., Habib, A., John, C.T., Guendelman, E., Thelen, D.G.: OpenSim:open-sorce software to create and analyze dynamic Simulations of movement. IEEE Trans. on Biomedical Engineering 55, 1940–1950 (2007)

[3] Holzbaur, K.R., Murray, W.M., Delp, S.L.: A model of upper extremity for simulating musculoskeletal surgery and analyzing neuromuscular control. Ann. Biomed. Eng. 33(6), 829–840 (2005)

[4] Cifrek, M., Medved, V., Tonkovic, S., Ostojic, S.: Surface EMG based muscle fatigue evaluation in biomechanics. Journal of Clinical Biomechanics 24, 327–340 (2009)

[5] González-Izal, M., Malanda, A., Navarro-Amézqueta, I., Gorostiaga, E.M., Mallor, F., Ibañez, J., Izquierdo, M.: EMG spectral índices and muscle power fatigue during dynamic contractions. Journal of Electromyography and Kinesiology 20, 233–240 (2010)

[6] Bonato, P., Gagliati, Knaflitz, M.: Analysis of myolectric signals recorded during dynamic constractions. IEEE Eng. Med. Biol. Mag. 15(6), 102–111 (1996)

[7] Hyper project, `http://www.iai.csic.es/hyper/contacts.html`

[8] Bueno, D.R., Montano, L.: An Optimized Model for Estimation of Muscle Contribution and Human Joint Torques from sEMG Information. IEEE Eng. Med. Biol. (August 2012)