An EMG-Driven Model to Estimate Knee Joint Moment

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Abstract: This paper presents a linear regression model to estimate knee joint moment from electromyography (EMG) and joint angle. Because the EMG signal reveals the neural command for muscle control, the proposed model is a key to develop the EMG-driven bionic limb. A teenager is the subject who is asked to take isokinetic exercises for knee extension and flexion in Biodex isokinetic dynamometer. The data such as EMG of rectus femoris and biceps femoris, knee joint angle, angular velocity, and moment are collected and analyzed. The raw EMG data are rectified and processed by moving average to obtain an envelope representing the trend of EMG. After a complete comparison, it is observed that the knee joint moment is highly correlated to EMG and joint angle. By using the least squares method the optimal solutions for linear regression models are solved that establish the EMG-angle-moment relationships for knee extension and flexion respectively. The models are validated by the fresh data which are not used in regression. The maximum percentage error of the optimal EMG-driven model is less than 25% in extension and under 21% in flexion.

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1. Introduction

A muscle contraction generates force to make human body movement. The Electromyography (EMG) is a very small voltage signal generated by the electricity activity of muscle fibers active during a contraction. During a particular task or exercise EMG can indicate whether the muscles are active and when the muscles initiate and cease that give an important understanding of the muscular function and state [1,2].

Yen et al. suggested that the vibration stimulation training improved the muscular performance of athletes by comparing EMG results [3]. Yasrebi et al. used EMG as an evaluation tool to investigate the effect of slopes change of motion surface on muscles fatigue of lower limb [4]. Sun et al. pointed out the characteristics of femoral muscles in knee isokenetic exercise from EMG [5]. Lloyd and Besier proposed an EMG-driven musculoskeletal model to estimate muscle forces and knee joint moments by measured EMG signal [6]. Kiguchi and Hayashi developed an upper-limb power-assist exoskeleton robot that was EMG-based control. The weighting matrix between muscle EMG and joint torque was on-line adjusted by a neuro-fuzzy modifier [7]. A lot of researches on EMG provide valuable information for many fields such as medical research, rehabilitation, ergonomics, and sports science [8].

In this paper an EMG-driven model to estimate knee joint moment according to EMG signal and joint kinematics (joint angle) is established. The experiment and method are explained in section 2. The results and discussion of signal processing and regression analysis are described in section 3. Section 4 concludes the paper.

2. Method

A male teenager (body mass 65.77 kg, height 171.1 cm, age 15) with no neuromuscular diseases history serves as the subject for this experiment. The subject is informed to carry out knee extension/flexion exercise 5 cycles at a controlled angular velocity 60°/s on the Biodex isokinetic dynamometer. The functions of isokinetic dynamometer is to isolate a lower limb, stabilize the adjacent segments, and control the speed of knee joint movement with varying resistance that is helpful to perform correct isokinetic test.

Two muscle groups—quadriceps femoris muscle group and hamstrings femoris muscle group—are considered in knee extension/flexion exercise. The quadriceps femoris muscle group, the producer of knee extension, consists of the rectus femoris, vastus lateralis, and vastus medialis. Its antagonistic muscle group, hamstrings femoris muscle group, contributing to knee flexion consists of the biceps femoris, and semimembranosus, and semitendinosus. In this study the rectus femoris and biceps femoris are selected for the observation of their EMG signals during knee isokinetic test.

There are two different ways to acquire EMG signal: needle and surface EMG techniques. The needle technique uses fine wire electrodes to acquire EMG signal by inserting the needle into the muscle tissue. In contrast, the surface technique uses non-invasive skin surface electrode. The needle technique provides the more accurate EMG data suitable for diagnostic applications; however, it is painful to subjects. On the other hand, the painless surface technique has major applications in movement analysis, prosthesis control, and biofeedback applications [2].

The surface EMG technique is used in this study. It requires surface electrodes, amplification, and data acquisition device to record the EMG signal. The NORAXON TeleMyo 2400T G2 is used to acquire data which includes surface EMG electrode leads with pre-amplifiers (common mode rejection ratio > 100 dB, input range ±3.5 mV, gain 500), hardware filter (all surface EMG electrode leads have 1st order high pass filters set to 10 Hz, all channels have low pass anti-alias filters set to 1500 Hz), and transmitter data acquisition system (16-bit resolution, sampling frequency 1500 Hz). The measurement setup and important signal check procedures such as the proof of the EMG signal validity and inspection of the raw EMG-baseline quality are carried out in the software environment NORAXON MyoResearch XP [8-10].

In addition to EMG data of rectus femoris and biceps femoris, the correlated data of knee joint angle, angular velocity, and moment are recorded simultaneously too. In order to figure out a model to predict knee joint moment, the signal-processing procedure and regression are applied. The signal-processing procedure includes full-wave rectification, moving average smoothing of EMG data, and data comparison by 2-D and 3-D plot. The knee joint torque can be modeled by a linear function of EMG and joint angle. By applying the least squares method to solve the optimal problem the linear regression model from empirical data can be obtained. The signal processing and linear regression are completed in the high-level computing software MATLAB and the data visualization software Tecplot.

3. Results and Discussion

3.1 Signal Processing

Figure 1 presents a global view of the raw EMG of rectus femoris and biceps femoris associated with knee joint moment and angular velocity in isokinetic exercise. In every cycle of knee extension-flexion, the period of positive angular velocity 60°/s represents knee extension and the period of negative angular velocity -60°/s represents knee flexion. A muscle action potential produced by nervous contraction command results in a burst of EMG signal. As shown in Figure 1, the rectus femoris is activated during knee extension and relaxed during knee flexion. In contrast the biceps femoris is activated during knee flexion and relaxed during knee extension. The EMG clearly indicates muscles activities.

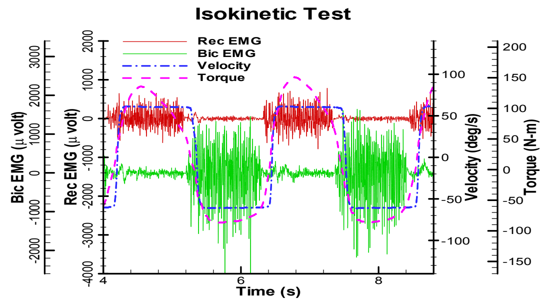

Figure 1. Raw EMG data and associated knee joint moment and velocity in isokinetic exercise

The full-wave rectification of EMG signal is shown in Figure2. Rectification is to convert all negative amplitude to positive amplitude, i.e., taking the absolute value of raw EMG signal. The envelopes of the rectified EMG obtained by moving average smoothing are also depicted in Figure 2. As the pattern of EMG is of random nature, the EMG cannot be reproduced by a specific shape. In order to increase reliability and validity of findings from EMG signal, the smoothing method is applied to outline the mean trend of EMG signal. The resulting linear envelope provides clear curve characteristics that would be helpful to examine the relationship between kinetics and EMG.

Figure 3 and 4 present the linear envelopes of rectified rectus femoris EMG and biceps femoris EMG by using moving average smoothing with different span. Increasing the span has two effects. First the smoothness of envelope becomes much better. Second the risk of a phase shift in contractions with steep signal increase needed to be considered becomes higher. In this study the span of moving average is chosen to be 450 points (0.3 s). The resulting EMG data processed by moving average smoothing are used in the following analysis.

To realize the relation between EMG and joint moment we plot joint moment vs. rectus femoris EMG for 4 acts of extension in Figure 5, joint moment vs. biceps femoris EMG for 4 acts of flexion in Figure 6. The joint moment is directly proportional to the EMG data in a certain range regardless of knee extension or flexion. In addition, the joint moment vs. joint angle is shown in Figure7 for knee extension and Figure 8 for knee flexion. It seems that there is a approximately linear relation between joint moment and angle during extension for joint angle θ within 25°-50° and during flexion for θ within 20°-40°. In order to visualize the relation among EMG, joint angle and moment, we express those data in a three-dimensional plots shown in Figure 9 and 10. The same patterns of three-dimensional lines for 4 acts of knee extension and flexion are clearly observed. In the next section we are going to build models by regression analysis to quantitatively represent the patterns.

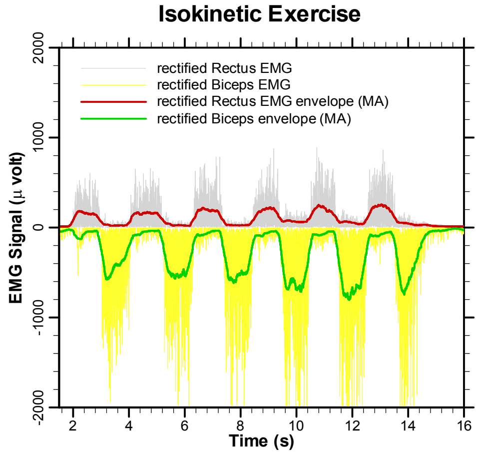

Figure 2. Rectification and smoothing of EMG

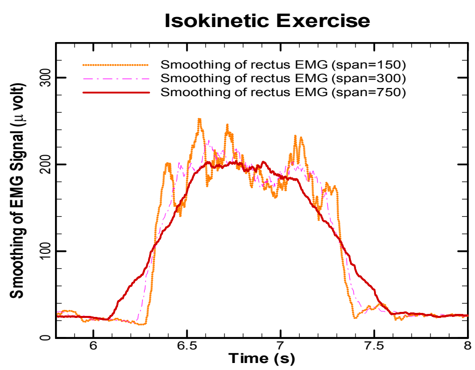

Figure 3. Comparison of moving average smoothing of rectus femoris EMG with different span

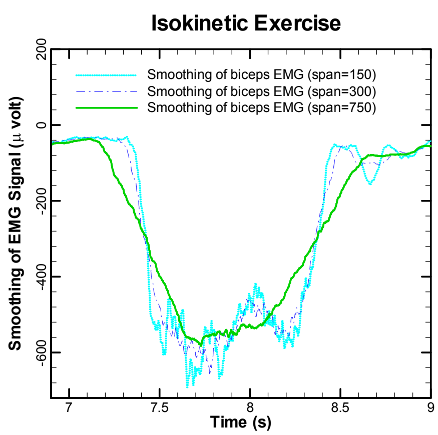

Figure 4. Comparison of moving average smoothing of biceps femoris EMG with different span

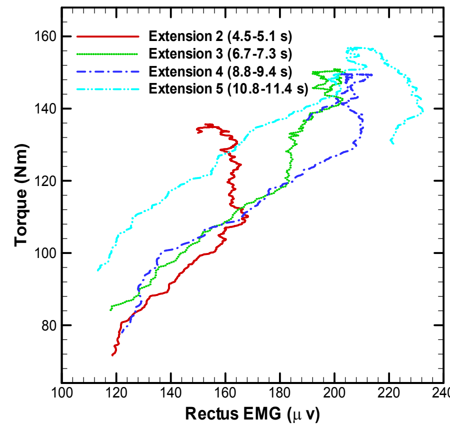

Figure 5. Knee joint moment vs. rectus femoris EMG for 4 acts of knee extension

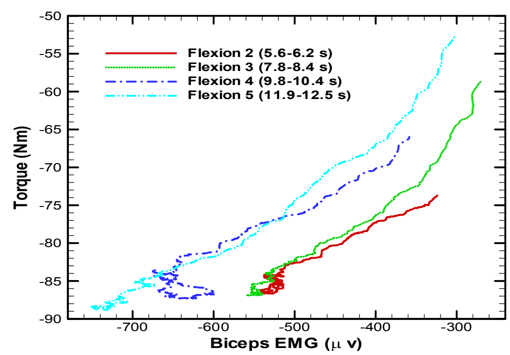

Figure 6. Knee joint moment vs. biceps femoris EMG for 4 acts of knee flexion

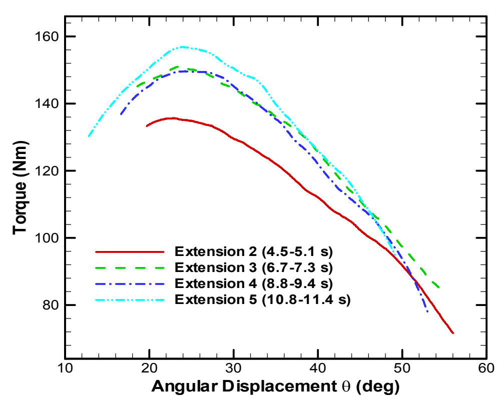

Figure 7. Knee joint moment vs. joint angle for 4 acts of knee extension

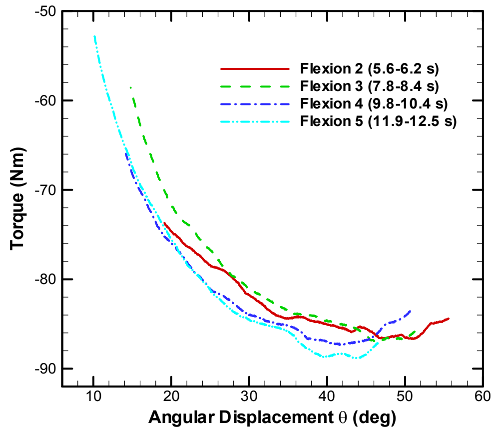

Figure 8. Knee joint moment vs. joint angle for 4 acts of knee flexion

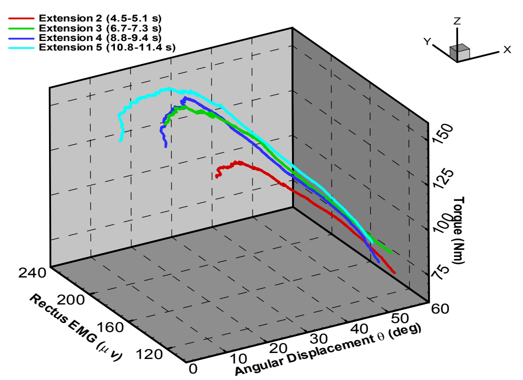

Figure 9. 3-D plot of knee joint angle, rectus femoris EMG, and joint moment for 4 acts of knee extension

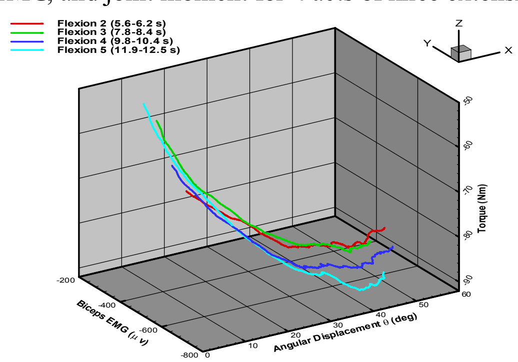

Figure 10. 3-D plot of knee joint angle, biceps femoris EMG, and joint moment for 4 acts of knee flexion

3.2 Regression Analysis

Consider the block diagram shown in Fig. 11. The inputs to the model are joint angle and EMG data, specifically rectus femoris EMG data for knee extension and biceps femoris EMG data for knee flexion. The model output is knee joint moment. From the above observation the knee joint moment is assumed to be a linear function of joint angle and EMG data. The linear equation can be expressed in a matrix form as

$$T = \begin{cases} XA, & \text{for knee extension} \\ XB, & \text{for knee flexion} \end{cases}$$

where

$$T = \begin{bmatrix} m_1 \\ m_2 \\ \vdots \\ m_n \end{bmatrix}, \quad X = \begin{bmatrix} 1 & \theta_1 & \Phi_1 \\ 1 & \theta_2 & \Phi_2 \\ \vdots & \vdots & \vdots \\ 1 & \theta_n & \Phi_n \end{bmatrix}$$

$$A = \begin{bmatrix} a_0 \\ a_1 \\ a_2 \end{bmatrix}, \quad B = \begin{bmatrix} b_0 \\ b_1 \\ b_2 \end{bmatrix}$$

T is the vector of knee joint moment m_i, X is the matrix of joint angle data θ_i and EMG data Φ_i, A is the vector of coefficients a_i to be solved for knee extension, and B is the vector of coefficients b_i to be solved for knee flexion. Applying the least squares method the solution for A_i and B_i with respect to each act is obtained. Table 1 and 2 present the maximum percentage error between estimated knee joint moment and actual moment for extension model A_i and flexion model B_i in every act. As a result of Table 1 and 2, the optimal extension model is

$$A_3 = \begin{bmatrix} 75.73 & -0.84 & 0.44 \end{bmatrix}^T$$

where the maximum percentage error is less than 25%; the optimal flexion model is

$$B_4 = \begin{bmatrix} -35.61 & -0.19 & 0.08 \end{bmatrix}^T$$

where the maximum percentage error is under 21%. Finally Fig. 12 and 13 show the percentage error versus joint angle for different acts of the optimal extension/flexion models.

Table 1 Maximum percentage error of the extension models A_i for 4 acts in knee extension

	A_1	A_2	A_3	A_4
Act 2	4.69	14.28	12.66	64.97
Act 3	9.90	5.65	8.01	38.32
Act 4	14.89	10.63	8.68	48.82
Act 5	33.06	30.01	24.13	9.93

Table 2 Maximum percentage error of the flexion models B_i for 4 acts in knee flexion

	B_1	B_2	B_3	B_4
Act 2	2.40	7.58	8.62	20.69
Act 3	21.01	9.46	10.53	17.76
Act 4	13.68	15.49	5.77	10.25
Act 5	36.74	26.92	24.24	11.38

Figure 11. Block diagram of regression model

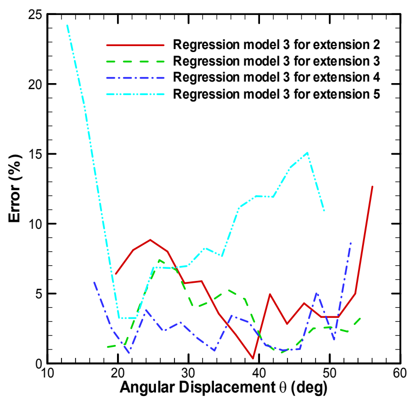

Figure 12. Percentage error vs. joint angle of the optimal model A_3 for 4 acts in knee extension

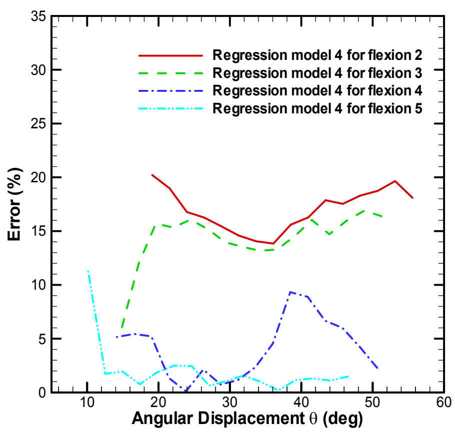

Figure 13. Percentage error vs. joint angle of the optimal model B_4 for 4 acts in knee flexion

4. Conclusion

This paper has proposed an EMG-driven model to estimate knee joint moment from EMG signal and joint angle. The EMG data of rectus femoris muscle and biceps femoris muscle, as well as the kinetic data including the knee joint angle, angular velocity, and moment, are recorded in isokinetic exercise. After rectification and smoothing of the raw EMG signal, a linear envelope is determined that outlines the mean trend of muscle activity. By applying the least squares method the regression models are solved. The maximum percentage error of the optimal extension model is less than 25% and that of the optimal flexion model is less than 21%. The results indicate that the regression models are useful to estimate the knee joint moment by EMG and joint angle.

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References

1. Hamill, J. and Knutzen, K. M. Biomechanical basis of human movement, 2nd Ed. Lippincott Williams & Wilkins, 2003
2. Merletti, R. and Parker, P. Electromyography: physiology, engineering, and noninvasive applications. IEEE Press, 2004
3. Yen, K.-T., Tsai, C.-T. and Chang, K.-Y. Effects of vibration training combined with plyometric training on muscular performance and electromyography. Life Science Journal, 2010, 7(1):78-82
4. Yasrebi, B., Leilnahari, K., Esmaeel, S. H.-A. and Salehian, M. H. Surface slope enhances anterior muscles fatigue in lower limb. Life Science Journal, 2012, 9(4):1410-1412
5. Sun, Y.-P., Yen, K.-T., Kung, H.-K., Tsai, Y.-C., Lu, K.-C., Du, C.-M. and Liang, Y.-C. The muscular function for human knee movement revealed from electromyography: a preliminary study. Life Science Journal, 2012, 9(1):453-456
6. Lloyd, D. G and Besier, T. F. An EMG-driven musculoskeletal model to estimate muscle forces and knee joint moments in vivo. Journal of Biomechanics, 2003, 36:765-776
7. Kiguchi, K. and Hayashi, Y. An EMG-based control for an upper-limb power-assist exoskeleton robot. IEEE Transactions on System, Man, and Cybernetics –Part B: Cybernetics, 2012, 42(4):1064-1071
8. Konrad, P. The ABC of EMG. NORAXON Inc. U.S.A., 2005.
9. TeleMyo 2400T G2 transmitter user manual. NORAXON Inc. U.S.A., 2007.
10. MyoResearch XP main manual. NORAXON Inc. U.S.A., 2004.

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