ESTIMATION OF KNEE EXTENSION MOMENT CONSIDERING VELOCITY EFFECT AND MUSCLE ACTIVATION USING TENDON SLACK LENGTH OPTIMIZATION

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This study presents a model to estimate knee extension moment considering muscle velocity effect and muscle activation. The muscle tendon force is very sensitive to the tendon slack length. To predict tendon slack length, exact muscle parameters of a human are needed. But it is difficult to measure all of the muscle parameters from human body. So we propose the algorithm which finds the tendon slack length of quadriceps for more accurate estimation of knee extension moment. Finally considering muscle velocity effect and muscle activation, knee extension moment is estimated. Algorithm was embodied by MATLAB optimization toolbox. And it is evaluated by using an experimental data.

KEY WORDS: tendon slack length, optimization, EMG, knee joint moment.

INTRODUCTION: This research is the basic research of developing gait orthosis for rehabilitation of a handicapped person. Orthosis should grasp the intention of human movement. By analyzing this intention, proper force will be estimated and delivered to human. For this process, accurate muscle skeleton model parameters are needed to estimate proper force, i.e. joint moment. Also muscle-tendon length which is changed by joint movement and moment arm should be searched. But those parameters can be hardly found for a specific person. S. L. Delp referred reported data until 1990, and defined muscle-tendon parameters of 43 muscles related to movement from young cadavers. Using these data he developed SIMM(Software for Interactive Musculoskeletal Modeling) which is muscle-skeleton movement analysis program. L. L. Menegaldo using this program, he proposed a function expressed by muscle length and variation of joint moment arm with the angle of joint.

But these parameters can not be a method of prediction for joint moment because every human has different values of muscle parameters. When we change tendon slack length, l_t^s and maximum isometric muscle force, F_0^m which are the most sensitive parameters related to muscle tendon force(F^t), it is expected that more accurate analysis will be executed.
In this paper, to solve this problem we will discuss about the method to decide tendon slack length and maximum isometric muscle force which is the most important element, using specified person's knee joint isometric extension moment in MVC(Maximum Voluntary Contraction) condition. And finally using optimized tendon slack length, optimized scale factor for maximum isometric muscle force, velocity effect and muscle activation, isokinetic extension moment can be estimated.

METHOD: Data Collection: Using a dynamometer, CON-TREX MJ system, isometric knee extension moment and isokinetic concentric knee moment were measured during the experiment. Isometric extension moment was collected in MVC (Maximum Voluntary Contration) condition. The process of isometric moment experiment was that a subject put forth his strength 2 times to extensional direction for 5 seconds of each one. Isometric knee extension moment was measured at 10°, 30°, 50°, 60°, 70°, 80°, 90° and 100°.

The isokinetic moment was collected at 30, 60 and 180 deg/s. Surface type EMG sensors are on the thigh to RF(Rectus Femoris), VM(Vastus Medialis) and VL(Vastus Lateralis) during the whole session. So muscle activations, a(t) can be calculated from processing those EMG signals. The subject sitting on the dynamometer at 85° hip angle had executed experiment only changing knee joint angle. And each maximum moment of each joint angle was selected for estimating knee extension moment.

Data Analysis: The Hill type muscle model was used for estimating joint moment.

$$F_t = \left\{ f_{act}(a(t), \tilde{l}_m)\, f(v) + f_{psv}(\tilde{l}_m) \right\} F_0^m \cos\phi \qquad (1)$$

Where a(t) is muscle activation, f_{act} is active muscle force term, f_{psv} is passive muscle force term, $f(v)$ is muscle force related to muscle contraction velocity, F_0^m is maximum isometric muscle force, $\tilde{l}_m$ is normalized muscle length and ϕ is pennation angle.

Equation (1) can be derived into equation (2) considering isometric contraction condition which is that muscle activation is 1 in MVC (Maximum Voluntary Contraction) condition and muscle velocity is 1 due to no movement during the isometric contraction.

$$\overline{F^t} = \left\{ f_{act}(\tilde{l}_m)\big|_{a(t)=1} + f_{psv}(\tilde{l}_m) \right\} \cos\phi \qquad (2)$$

$$\overline{F^t} = \begin{cases} 1480.3\varepsilon^2 & 0 < \varepsilon < 0.0127 \\ 37.5\varepsilon - 0.2375 & \varepsilon \geq 0.0127 \end{cases} \qquad (3)$$

$$\varepsilon = \frac{l^t - l_s^t}{l_s^t} = \frac{l^{mt}(\theta) - l_o^m \tilde{l}_m \cos\phi - l_s^t}{l_s^t} \qquad (4)$$

Where l^t is tendon length
l_s^t is tendon slack length
l^{mt} is muscle tendon length
l_o^m is optimal muscle length

For the reliable estimated knee joint moment, model parameter values for each muscle are needed. Also Menegaldo's formula have to be applied to variation of muscle length and moment arm. But changes of muscle-tendon length due to muscle contraction or relaxation or each muscle character parameters are not measurable. However if the structure of muscle-skeleton is similar to each other, appropriate size scaling can help using data from S. L. Delp or L. L. Menegaldo. The optimization algorithm was built for finding tendon slack length and scale factor k which is minimizing the differences of calculated knee extension moment from experimental data by MATLAB optimization toolbox. The algorithm is designed on the assumption that muscle force characteristics of each individual can be expressed by controlling values of tendon slack length(l_s^t) of each muscle and maximum isometric force(F_0^m). To minimize the number of optimization variables, just one scale factor (k) is used for RF, VM and VL instead of optimizing F_0^m of every muscle. Delp's data of tendon slack length and k=1 were used for initial values of optimization. Each optimized tendon slack length and k from the optimization algorithm in figure 1 are listed in table 1.

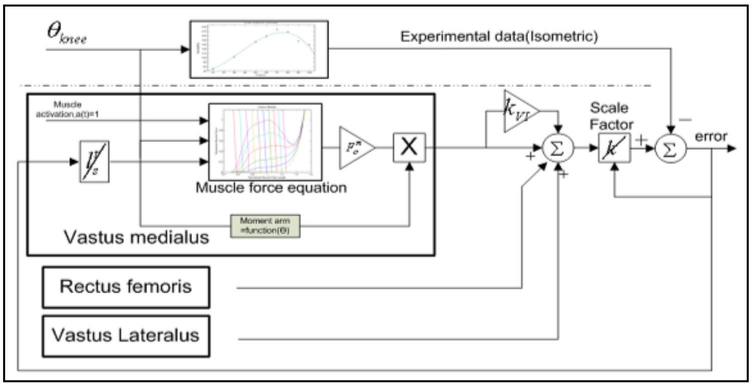

Figure 1: An optimization algorithm for tendon slack length and moment scale factor.

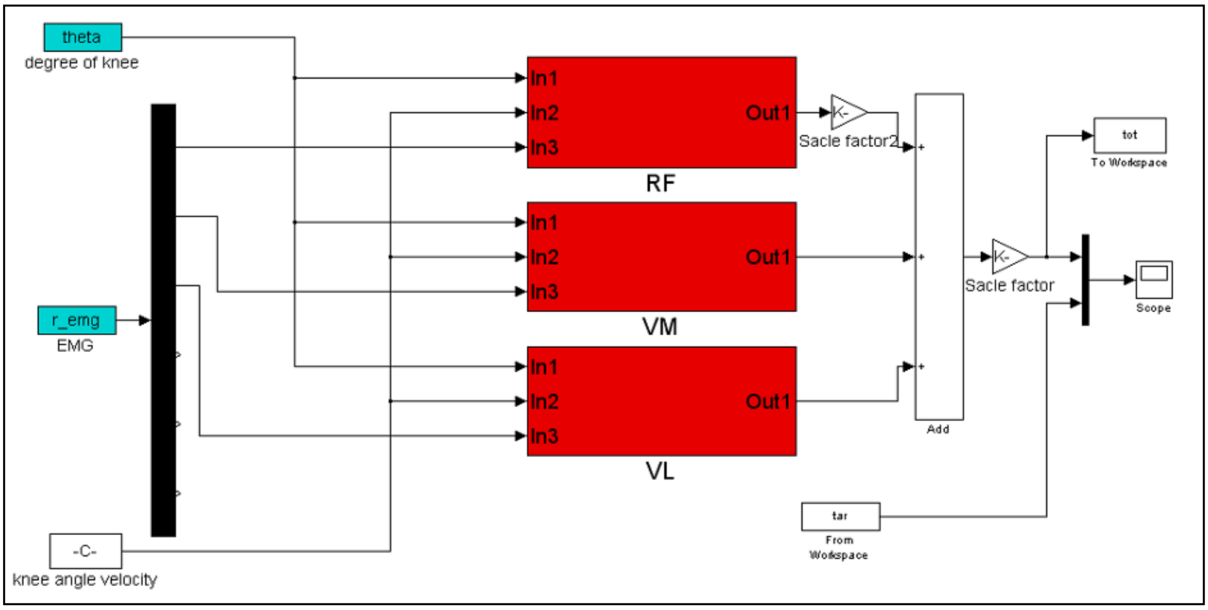

Figure 2: An algorithm estimating knee extension moment

RESULTS: After getting each optimized tendon slack length of RF, VM and VL and optimized scale factor k, to estimate isokinetic extension moment, input parameters of l_s^t, k, a(t), knee angle, muscle velocity and muscle parameters were allocated in the algorithm in figure 2.

The result of estimated knee isokinetic extension moment after performing the algorithm in figure 2 is showed in figure 3

Although the RF, VM, VL and VI(Vastus Intermedius) is the most influential muscle to generating knee extension moment, only RF, VM and VL were used due to not attaching an EMG sensor on VI. Assuming that PCSA (Physiological Cross Sectional Area) ratio of each muscle related knee joint extension will be invariable for each individual, a scale factor for VI considering PCAS ratio is multiplied to RF because of RF having similar patterns of the EMG signal to VI.

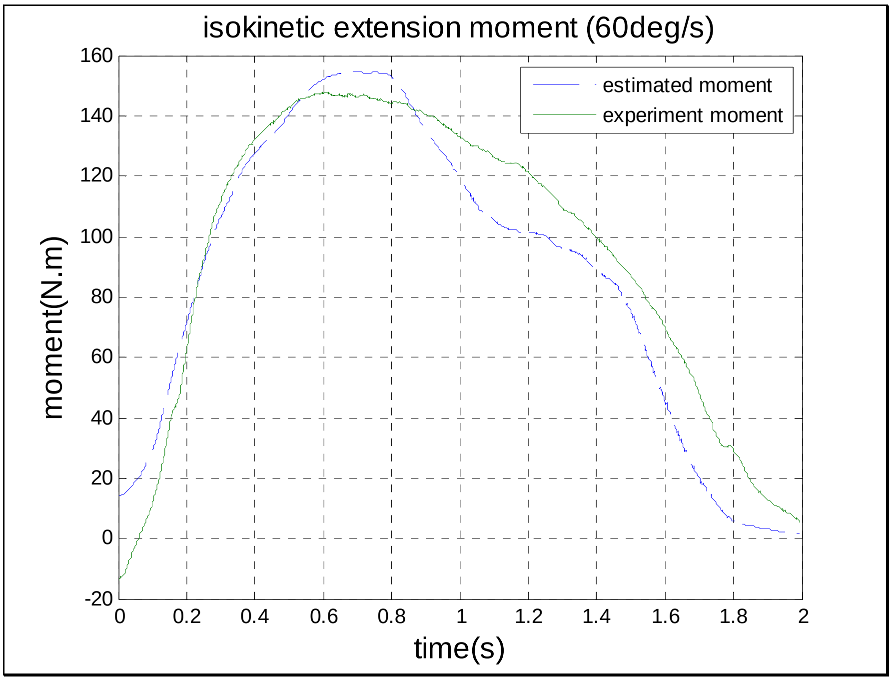

Figure 3: Estimated knee isokinetic extension moment in 60deg/s

Table 1 optimized tendon slack length and scale factor

	A: Initial values (Delp)	B: optimized values	(A-B)/A(%)
$l^t_{s\,RF}$	0.346	0.3239	6.387
l^t_{sVM}	0.126	0.1299	-3.095
l^t_{sVL}	0.157	0.1490	5.096
k	1	1.4361	-43.61

In table 1, l^t_s and k which were calculated after the optimization process by using MATLAB optimization toolbox in figure 1 are indicated. Searching range for tendon slack length is ±15 and ±50 for scale factor. The initial tendon slack length values of each muscle were refered to the paper of S. L. Delp.

DISCUSSION:

To estimate joint moment, precise musculotendon parameters are needed. However it is pretty difficult to know accurate musculotendon parameters of specified person. Optimization algorithm for estimating joint moment was designed with finding values of tendon slack length and scale factor k. Change of searching range of tendon slack length and k makes considerable differences between experimental moment and estimated moment. The best matching factors are selected for the optimization.

CONCLUSION: Tendon slack length is the most sensitive and important parameter to determine muscle tendon force. So adjusting tendon slack length of the muscles and scale factor k, expected knee extension moment is approximately matched with experimental data. Muscle activation derived from processing EMG signals and muscle velocity also used for algorithm of estimating knee extension moment.

This study can help analyzing the intention of movement by using EMG signals and kinematic information to help handicapped person with gait orthosis.

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